D5.5 – Canvas business models for the most promising system concepts

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List of acronyms and abbreviations

ABEP	Atmosphere Breathing Electric Propulsion
AIS	Automated Information System
AOI	Area Of Interest
API	Application Programming Interface
CDTI	Centro para el Desarrollo Tecnológico Industrial
COTS	Commercial Off – The – Shelf
DAP	Digital Access Pass
DISCOVERER	Disruptive Technologies for Very Low Earth Orbit Platforms
DMC	Disaster Management Constellation
EO	Earth Observation
ESA	European Space Agency
EU	European Union
GBDX	Geospatial Big Data Platform
GEO	Geostationary Orbit
GEOINT	Geo – Intelligence
GIS	Geographic Information System
GSD	Ground Sample Distance
IMINT	Imaginary Intelligence
JAXA	Japan Aerospace Exploration Agency
LBS	Located-Based Services
LEO	Low Earth Orbit
MCOP	Mega - Constellation Operations Platform
NASA	National Aeronautics and Space Administration
NGA	National Geospatial – Intelligence Office (U.S.)
NOAA	National Oceanic and Atmospheric Administration (U.S)
NGO	Non – Governmental organization
OCS	Operational Control System
R&D	Research and Development
SAR	Synthetic Aperture Radar
SSO	Sun – Synchronous Orbit
UAV	Unmanned Aerial Vehicle

UHD	Ultra High Definition
UPC	Universitat Politècnica de Catalunya
U.S. DoD	United States Department of Defence
UV	Ultra Violet
VAS	Value-Added-Services
VHR	Very High Resolution
VHR-HP	Very High Resolution – High Performance
VHR-LC	Very High Resolution – Low Cost
VLEO	Very Low Earth Orbit
WP	Work Package

1 Executive summary

The aim of this document is to produce a set of Business Models (BM) for the most promising concepts of exploitation of VLEO for EO purposes. The starting point for producing this document is two folded:

- In the previous *Deliverables D5.1 and D5.3*, an up-to-date analysis of the **EO market** has been conducted. D5.1 deals with the present EO market, and D5.3 with the **trends for EO at VLEO**. As a result, both the present stakeholders, and the expected growth of the market, arise.
- *Deliverable D5.2* makes a deep analysis of the **benefits and challenges of VLEO for EO** purposes, and *Deliverable D5.4* draws the most **promising system concepts of platforms** suited to the DISCOVERER technologies.

Some **context** figures (*table 4.1*):

- **19% of all satellites** launched so far are devoted to EO.

Table 4.1. Summary of EO market (Deliverable D5.1) Source [1]

	2007-2016	**2017-2026**
Type of prominent operator	Governments	Commercial operators
# Countries with EO satellites	35 + ESA	48 + ESA
Total launched EO satellites (>50 kg)	181	601
Manufacturing Revenues	$17.4 billion	$33.6 billion
Cumulated Commercial data revenues	13.5	25
Cumulated VAS revenues	22.6	47

When defining the new BM for EO at VLEO, an **exhaustive analysis** of several present companies has also been performed and the **BM of eight companies** has been created. The companies are: *Planet, DigitalGlobe, Urthecast, Satellogic, Deimos, Spire Global, GomSpace, and Space Flight*. Each of the case studies is related to a more extensive analysis in its respective *Attachment*.

The **success factors analysis** of those companies lets to identify one general strategic behaviour pattern, the **Democratizing Pattern**, that has been extrapolated to every new BM. The five main characteristics of this new pattern are:

- The companies face an open market with an increasingly number of new customers.
- The companies have (need) a large partnership network.
- The companies tend to offer low prices for the added-value services.
- The companies devote efforts in reducing their variable costs.
- The companies offer tools for an automatic relation with their customers.

This pattern allows the identification of five virtuous cycles in the BM feedback loops (Methodology: *Casadesus and Ricart (2010), figure 7.21*):

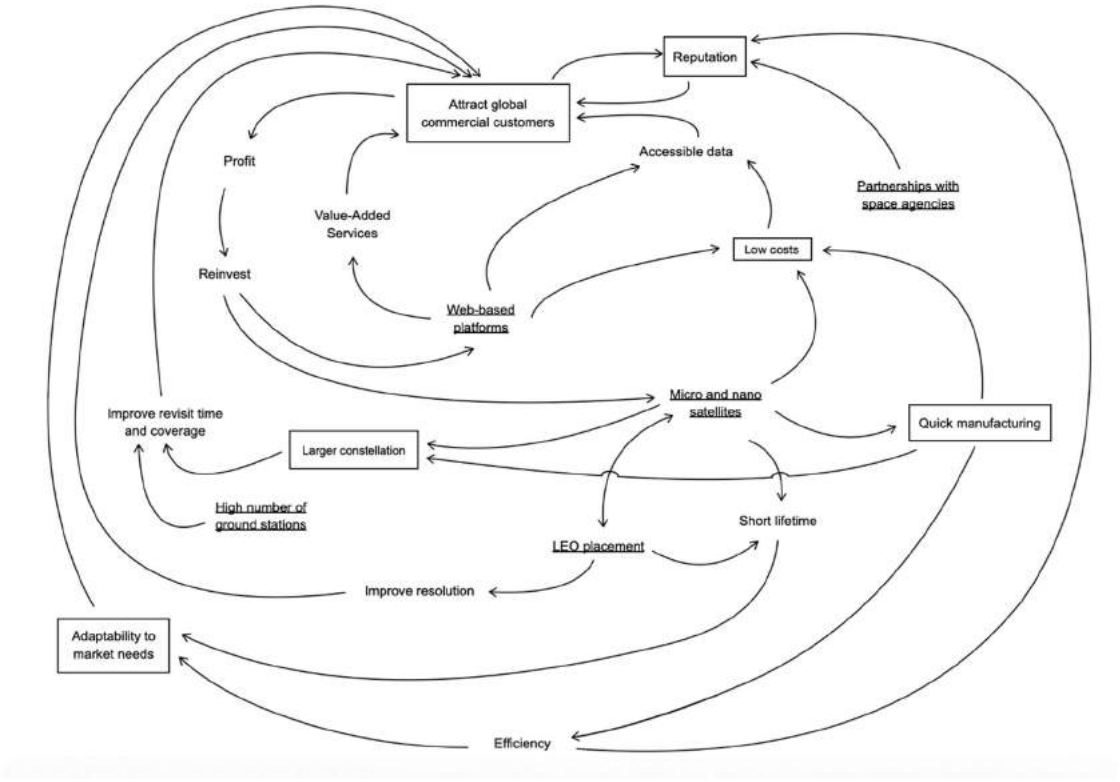

Figure 7.21. Feedback Loop Diagram for the Democratizing Pattern

The analysis of the **market trends** and the **new system concepts**, including the previous **success factors** produces a set of promising Business Models:

- **Access to space** at lower orbits and smaller satellites is gaining the attention of several projects. *This deliverable suggests some key operational aspects to be considered by those projects and the coming ones*.
- The increased number of missions and the reduced communication windows at lower orbits, will see a growth in the number of **ground stations** and some capacity aggregation will be necessary. *This deliverable foresees new BM for those activities*.
- The increasing number of satellites by different stakeholders will also see an increasing demand for **space brokers or turnkey providers** that can fulfil some of the necessary stages of a mission. *This deliverable analyses the aspects to be considered for the interested companies*.

Besides those VLEO related opportunities in terms of BM, **some promising concept platforms** have also been designed (*deliverable D5.4*) and their market approach has been analysed in this deliverable:

- Very High Resolution – High Performance platform (**VHP-HP**).
- Very High Resolution – Low Cost constellation (**VHP-LC**).
- Synthetic Aperture Radar (**SAROptic**).

Finally, those platforms are also analysed under the **Value Proposition CANVAS** (VPC) to also consider the integration of the DISCOVERER technologies:

- New materials with reduced drag and low erosion.
- New aerodynamic attitude and orbital control.
- New air breathing electric propulsion.

The results of this deliverable plus the work performed in the different DISCOVERER technologies will allow the production of **two sets of roadmaps focused on** the companies' Business Models and the Discoverer technologies for the future EU conquer of VLEO for EO purposes.

2 Introduction

The EU funded DISCOVERER project started in January 2017 aiming at identifying the technological challenges and suggesting improvement possibilities that may allow the commercial exploitation of near Earth Orbits (Very Low Earth Orbit) for Earth Observation purposes.

The project was started upon three technological research questions:

- *How can we improve our understanding of, and make best use of, the orbital aerodynamics of the space platform and its ability to perform attitude and orbit control manoeuvres?*
- *Are there propulsion methods which use the residual atmospheric gas as a propellant, providing drag compensation whilst removing the lifetime limits caused by carrying a limited amount of propellant?*
- *Are there materials or processes which reduce the induced drag on spacecraft surfaces?*

Plus, one additional, non-technological research question:

- *In case of technological success of DISCOVERER, what are the most promising business models that may allow exploiting VLEO for EO purposes?*

The DISCOVERER project is a FET proposal (Future Emerging Technologies) dealing with Technology Readiness Levels (TRL) still far from commercial application. Even though it is quite obvious that the successful commercial development of companies taking advantage of VLEO is based on the previous technological successes, and it may still take some years till possible; the WorkPackage WP5 of the project will provide some insights on how that commercial presence may look like.

This apparent incoherence in the early study of the future market prospects for EO at VLEO suggests that the best tools to be considered are the Business Models (BM), that provide an improved drawing of each Business Idea, even though, for obvious reasons, BM are not so detailed as a Business Plan may be.

3 Purpose

The aim of this document is to produce a set of Business Models (BM) for the most promising concepts of exploitation of VLEO for EO purposes. Even though the DISCOVERER project objectives are just related to the BM for the DISCOVERER technologies, this documents extends its scope to the whole VLEO exploitation spectrum.

The starting point for producing this document is two folded:

- In the previous Deliverables D5.1 and D5.3, an up-to-date analysis of the EO market has been conducted. D5.1 deals with the present EO market, and D5.3 with the trends for EO at VLEO. As a result, both: the present stakeholders, and the expected growth of the market, arise.
- Deliverable D5.2 makes a deep analysis of the benefits and challenges of VLEO for EO purposes, and Deliverable D5.4 draws the most promising system concepts of platforms suited to the DISCOVERER technologies.

As a result, this deep analysis of market and system concepts produces a set promising business ideas that become Business Models at the end of this document.

Thus, the structure of this deliverable is:

- **Introduction, Purpose, and Context** are explained in *chapters 2, 3 and 4*.
- The most advanced Business Models methodologies, namely **BM CANVAS** (*Osterwalder et Pigneur (2013)),* for an operational approach, and **BM Feedback Loop** (*Casadesus et Ricart (2010)*), for a strategic approach, have been described in *chapter 5*.
- The present **BM CANVAS for eight EO companies** (*Planet, Digital Globe, UrtheCast, Satellogic, Spire Global, Spaceflight, and the DISCOVERER partners Deimos and GOMSpace*) have been summarized in *chapter 6*. Besides, one specific Case Study for each of those companies is also presented in the Appendices of this deliverable.
- *Chapter 7* makes a deep analysis of **the success factors** of the previous companies in order to develop a new pattern that is common to all of them, the **Democratizing Pattern**.
- **Four promising system concepts and Business Ideas** defined at the previous deliverables are further analysed as new updated Business Models in *chapter 8* (two of the arisen promising concepts are already in operation as shown in *chapter 6* (*Very High Resolution – Low Cost platforms in Constellations, and SAROptic*)):
    - Access to Space → Micro-launchers, including rockoons.
    - Ground Station Services.
    - Space Brokers.
    - Very High Resolution – High Performance Platform.
- *Chapter 9* takes those previous platform concepts and combine them with the **DISCOVERER technologies**, in order to first set **new Value Proposition CANVAS**, and second include these new value propositions into existing EO companies in order to see how their respective BM CANVAS could change.
- *Chapter 10* will draw the **conclusions and recommendations** in order to go one step further in WP5, **linking with the technological and BM roadmaps** (deliverables D5.6 and D5.7, respectively).
- *Chapter 11* summarizes the **internal and external references** of this document.

4 Context: Space market and its strategy

This section summarizes what has been done in previous deliverables in order to present an overview of the current Very Low Earth Observation (VLEO) status and the space market trends.

4.1 Space market

Humans have looked up into the sky since they existed, but the space industry did not start until 1957 with the successful first artificial satellite mission, Sputnik 1. More than sixty years later, the space industry has become the centre of many innovations, and a new booming market playing an essential role in daily life.

Artificial satellites can be used for different applications depending on their mission. Some applications for satellites orbiting the Earth are weather forecasting, navigation, communications, astronomy, and Earth Observation (EO). Figure 4 .1 shows the current operational satellites divided by application.

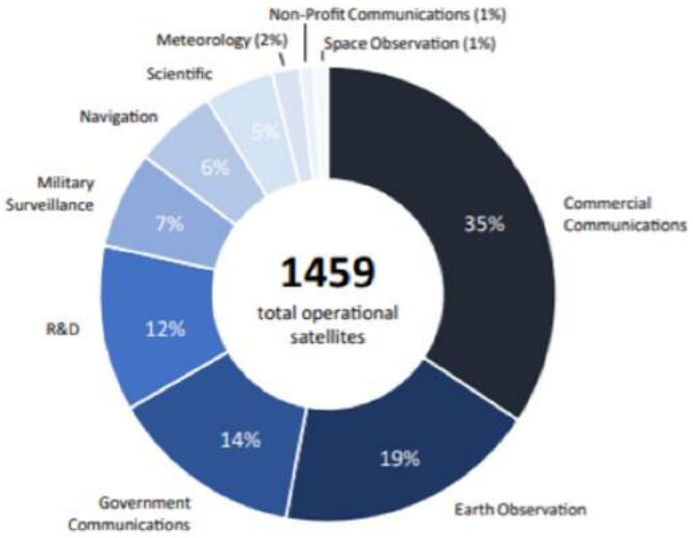

Figure 4.1 Operational satellites by applications, Source: [1]

In this study, the main focus is Earth Observation satellites with an especial interest in their commercial applications. That means 19% of all launched operational satellites.

4.2 Current EO market

At the present *Information Age*, power can be measured by the amount of information possessed by a country, and the World Powers are well aware of it.

Over the last decade, the number of satellites dedicated to Earth Observation has exponentially grown, and governments are the primary investor by financing military, civil and dual-use satellites. The global EO investment can be seen in Figure 4 .2.

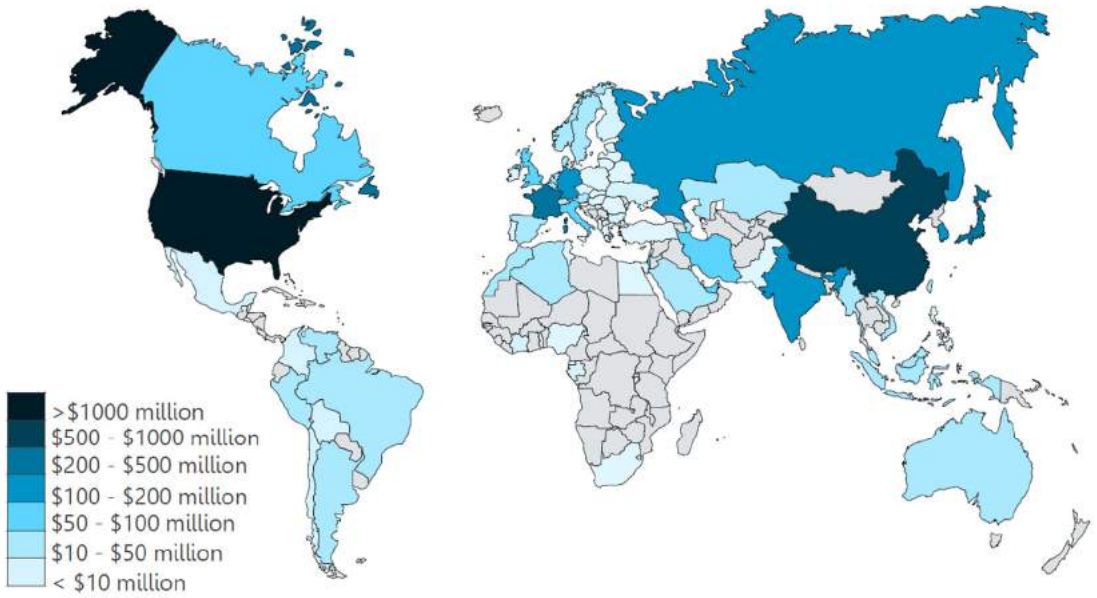

Figure 4.2 Global EO investment. Source: [2]

In the last few years, private EO companies have appeared in the market to provide images and low-cost satellites to society. The main difference between government satellites and those new ones is the target focus, public satellites being focused on one or two specific missions such as global warming or research, and the private ones are diversified towards a variety of clients. These new businesses, those providing value-added services (VAS) to the EO market, are processing and analysing the images before selling them.

Extended information about this can be found at *Deliverable D5.1* from the DISCOVERER project, and a summary of the main figures for the EO market are listed in Table 4.1.

Table 4.1 Summary of EO market (Deliverable D5.1) Source [1]

	2007-2016	**2017-2026**
Type of prominent operator	Governments	Commercial operators
# Countries with EO satellites	35 + ESA	48 + ESA
Total launched EO satellites (>50 kg)	181	601
Manufacturing Revenues	$17.4 billion	$33.6 billion
Cumulated Commercial data revenues	$13.5 billion	$25 billion
Cumulated VAS revenues	$22.6 billion	$47 billion

It is crucial to understand how the industry is distributed and adapted to the current market scheme. This sector is mainly split into two types of operators, upstream and downstream. The upstream operators are focused on manufacturing and sending objects into space and explore it while downstream uses that research and technology for different applications by processing and selling images and data.

Each stage has different characteristics, and they are split forward into investors, manufacturing, launching, ground segment (upstream - Figure 4 .3), data operation, distribution, and VAS (downstream

- Figure 4.4). Both figures, Figure 4.3 and Figure 4.4, present the value chain of the EO market (*see also Deliverable D5.1*).

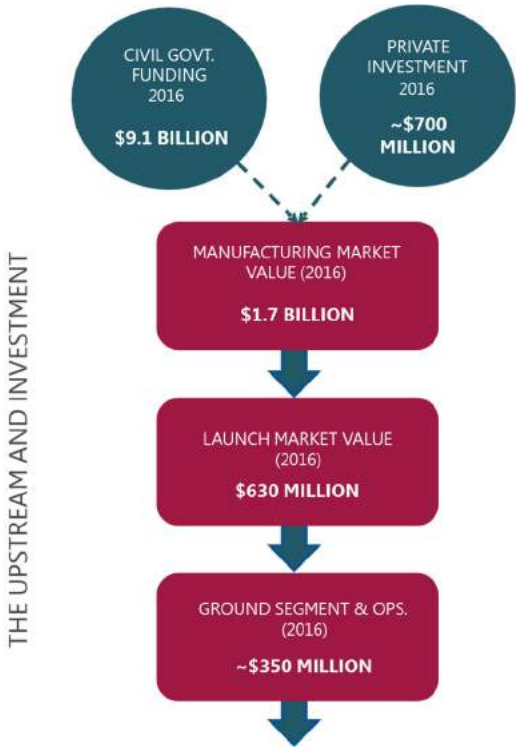

Figure 4.3 The EO upstream value chain. Source: [1]

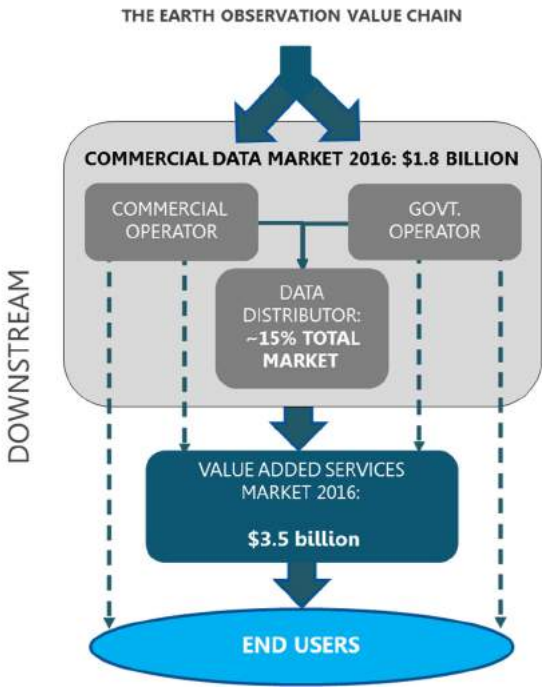

Figure 4.4 The EO downstream value chain Source: [1]

Examples of current and future capabilities of EO operators can be DigitalGlobe & MDA, Airbus Defence and Space, DMCii, Planet, Blacksky, Spire, Hera, and Uthercast. Some of these companies are studied along with this document in *Chapter 6* (*Existing Business Models*).

The exploitation of space resources is the most profitable activity, so downstream is where the more significant benefits can be found. In 2016 the cumulated turnover ratio was 3% for upstream and 97% for downstream with a total of 250 billion dollars. This means that the satellites' services and data providers are popular products, so it is easy to see why the most profitable sectors are Communication and EO.

Moreover, the space market (Figure 4.5) is changing and evolving to fulfil the needs of the society and new emerging services. This development is mainly caused by the inclusion of the private companies that add business model innovation with significant cost reduction besides new products.

In the following sections, some current business models and some new ones are shown to identify the change of the space market and its patterns.

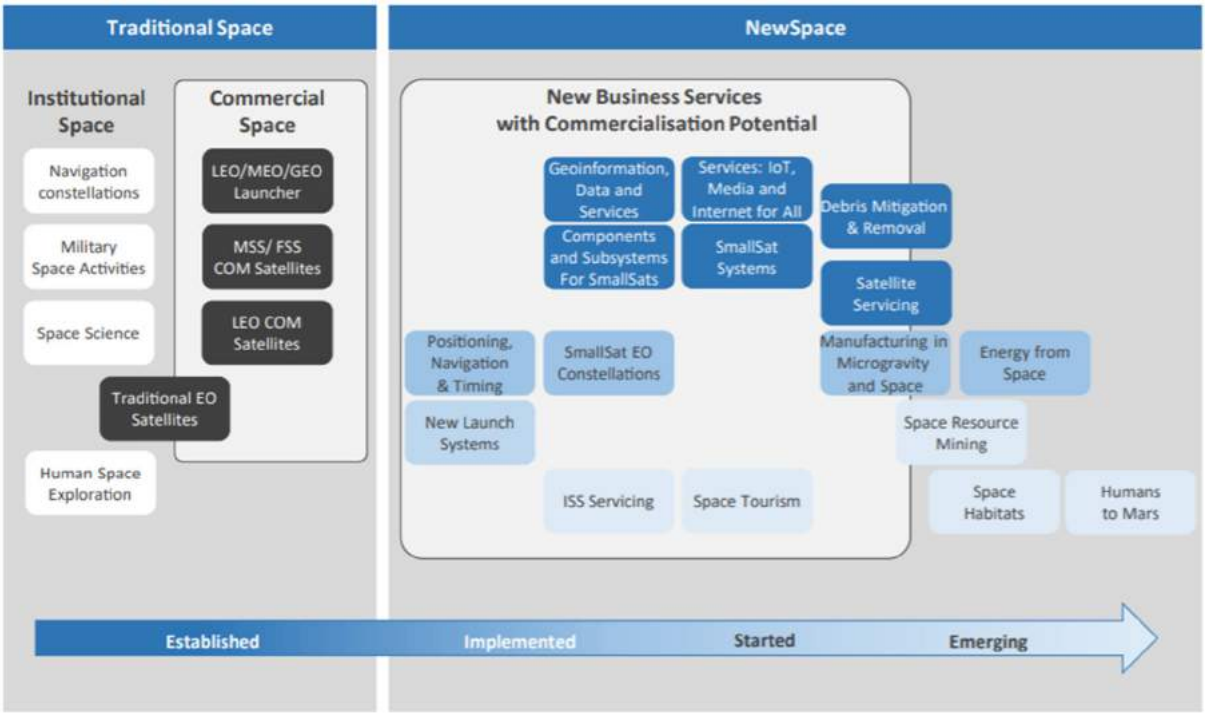

Figure 4.5 The Space market evolution. Source: [3]

As downstream is the most profitable segment, it is important to focus on the commercial data market and its business. In Table 4.2 presents the summary of the key results of *Deliverable D5.1*.

Table 4.2 Summary of Key figures on the EO commercial data market Source: [1]

	2007-2016	**2017-2026**
Cumulated all commercial data revenues	$13.5 billion	$25 billion
Main vertical market	Defence	Defence
Main data type	VHR	VHR
Main customer	U.S. DoD	U.S. DoD
Main customers region	North America	North America

In this document, the existing business models that have been studied to have a better understanding of the private upstream and downstream are *Planet, DigitalGlobe, UrtheCast, Satellogic, Deimos, Spire Global, GOMSpace, and Spaceflight*.

4.3 Very Low Earth Orbit characteristics

The DISCOVERER project is focused on providing solutions for VLEO. However, operating a satellite under 450 km has some specific particularities to be considered (*extracted from Deliverable D5.2)*.

VLEO orbits are **placed in the thermosphere**, the layer of the atmosphere between 95 km and the thermopause, varying with the solar radiation, the location, the time, the season, among others, and it can fluctuate between 500 and 1,000 km.

In this region, the atmosphere temperatures have very abrupt changes between day and night and climb fast with the altitude. In the upper thermosphere, the range can vary from 500 and 2,000ºC. Due to the

high temperatures and the UV solar radiation, the molecules are broken into atomic oxygen, so the main component in VLEO is the **atomic oxygen** with some atomic nitrogen and helium.

It is important to highlight that the variations of height of the thermosphere due to the solar radiation and the temperature changes affect the air density, which means that all satellites orbiting in VLEO not only have to **cope with drag but with force variations**.

The best way to introduce the VLEO orbits is by discussing their benefits and challenges. Let us summarize the keynotes of *Deliverable D5.2*:

- The sensor resolution of the spacecraft changes when changing its altitude. Spatial, geometric, temporal, and radiometric resolutions depend on the distance between the camera and the target, but the spectral resolution only depends on the equipment.
- Mapping errors as a result of attitude determination and pointing accuracy are reduced at lower altitudes, improving the geospatial accuracy of ground imagery and location-based services.
- The spatial resolution of a camera is directly related to the distance to the objective. Changing EO satellites from LEO to VLEO allows higher resolution for the same satellite or reduces the aperture of the sensor and the size of the spacecraft without reducing resolution.
- It is easily noticed that increasing spatial resolution by approaching the satellite to the Earth surface also reduces the spacecraft's swath, so its resolution gets worse than before.
- Another effect is that due to the lower altitude and the elevation angle constrains of the satellite, the available window for data downlink is reduced.
- The revisit time of a spacecraft is general worse in lower altitude orbits, though it is more complex to synchronize and control a constellation of satellites. Even though as the satellite is nearer to the Earth, the revisit period will be shorter.
- A short orbit cycle is not crucial in EO because having a repeating ground-track is not strictly required, though it helps capture regular images of a region and have lower revisit time. In VLEO, the perturbations of the residual atmosphere and the external satellite forces continuously change the orbit, so the repeating ground-tracks are only possible with new technologies such as aerodynamic control or propulsion.
- On the other hand, many EO small satellites orbiting in VLEO or LEO have a near-polar sun-synchronous orbit [4]. These orbits have a particular condition: the satellite covers a determinate area of the globe at a constant Sun time, providing the same illumination to the area in different acquisition times. These orbits at low altitude ranges have large revisit times, although the effect can be reduced using non-SSO orbits.
- The radiometric resolution can be improved by lowering the orbits of the satellites because the electromagnetic signal received by the sensor increases by reducing the distance to the target. Despite this, it is necessary to emphasize that at low orbits, the noise signal received at significant off-nadir angles might increase.
- Another benefit of flying a probe at 450 km is that the satellite would naturally deorbit at the mission ending without any extra propulsion because the atmosphere would re-enter any object in less than 25 years. This effect allows us to have a clean space environment and reduce possible debris collisions. Moreover, as the VLEO are not used yet, the amount of debris is reduced, provoking a safer environment for the satellite.
- Finally, a range of further benefits of operating at lower orbital altitudes exist that are yet to be accounted for in the system modelling framework, for example increased launch vehicle capability, reduced radiation exposure, and lower collision risk. Besides, significant uncertainty also remains in the development and implementation of the enabling technologies.

All these benefits and challenges are trying to be exploited and solved in the DISCOVERER project framework by studying aerodynamics, materials, and propulsion system that a satellite in VLEO would have and need.

4.4 New market opportunities

WP5 is focused on studying the **system concepts** implications and **applications** in the DISCOVERER technologies such as ABEP, aerodynamic control, and materials which are studied in chapter 8 and 9 in more detail.

Deliverable D5.4 - System Models Description of VLEO Platforms with Promising Opportunities in the EO market mentioned four promising systems concepts that can be performed at VLEO and they are classified into four categories: VHR-HP; Constellation; VHR-LC and SAR Platforms. The business models for those concepts are developed in chapter 8.

One of those promising concepts is the **very high resolution-high performance satellites** (VHR-HP). This platform let the distance from the target to be reduced and so the imaging requirements allow the companies to achieve higher stability and quality. There are some existing satellites with these characteristics, such as the *WorldView-1, -2, -3* among others. They are mainly used in defence, infrastructure and location-based services (LBS) markets.

Another promising EO concept is the **very high-resolution low-cost satellites** (VHR-LC). This market is focused on providing sub-metric resolution and high-revisit time at an affordable price. They are used for precision agriculture, defence, energy and urban development markets. Some examples of companies that are currently working under this kind of business model are *Blacksky and Satellogic*.

The last passive optical trending concept is related to the **Coverage**, satellites with lower spatial resolution than the previous ones but with wider swatch and higher temporal resolution. Some examples of **optical high-resolution coverage** can be, for instance, *Satellogic and Planet*. These satellites have a high response due to the **frequent data collection** and can be used for mapping, humanitarian and environmental monitoring, and disaster monitoring like the *Planet Dove CubeSats and DMC*.

Finally, the **Synthetic Aperture Radar** is also studied in *Deliverable D5.4* as a promising concept. The interest in these active satellites lies on their ability to provide new EO products without depending on the light and on the methodological conditions.

To have full knowledge and understanding of VLEO in the EO market, studying the possible different businesses that do similar activities is essential because they could act as competitors or partners.

Taking images of the Earth is not restricted to satellites; other devices such as UAVs, airships, balloons, probes, aircraft, etc. can do it. All of these options do not orbit the Earth so they cannot always be working. They need to know where to take the picture and be sent to the Earth's precise spot. These alternatives have some advantages and disadvantages, like a higher resolution and a great accuracy on the image without wasting resources but with the inability to monitor large areas along big periods.

These kind of businesses can be market competitors but also partners. Since it is possible to monitor a vast portion of the Earth with a satellite orbiting in VLEO and detect the precise spot that needs to be studied to send one of the other devices to take the final image.

Also, the business models of **new launching concepts** such as rockoons and micro-launchers are studied in chapter 8. These other companies have appeared around the EO market, providing access to space with new dedicated methods (see Deliverable D5.3) that differ from the typical rocket in which the satellite travels as a piggyback. Besides, *Deliverable D5.3* presents an increasing raise of other **new promising concepts**, especially suited for VLEO, such as space brokers or VHR-HP platforms also studied in chapter 8.

Other promising concepts shown in *Deliverable D5.3* such as "Global Coverage" or "Low Cost", since they are already applied in existing companies, will also be analysed in chapter 8 of this document.

5 Business Models Methodology

It is a well-known fact that there is not a globally accepted definition of a business model. As a consequence, not all definitions include the same components. For this reason, when trying to compare several business models, a framework plus a shared language is needed. It is strictly at that point where the business model methodologies play an essential role.

B.W. Wirtz et al. [5] claim that while in the early years, it was easy to identify whether a business model was defined from an operational, technological or strategic point of view, nowadays, definitions seem to converge towards a global understanding. However, those three points of view are not completely merged yet. Therefore, to provide an exhaustive analysis, more than one framework has to be applied.

Thus, this study opts to analyse the business models from two different approaches, one operational and another more strategic one. The methodologies that we will use for each case are the **Canvas** template and the **Feedback** loop diagram, respectively.

5.1 The Canvas template

"*A shared language for describing, visualizing, assessing, and changing business models*" [6] is how both authors, A. Osterwalder and Y. Pigneur, define the business model Canvas template. As aforementioned, this methodology is used to analyse the enterprise from an **operational** point of view. It represents, by means of **nine building blocks**, how the company organises itself to create, deliver and capture value.

5.1.1 Template representation

Before going deeper into describing the nine building blocks, it is vitally important to have a quick overview of the complete Canvas template (figure 5.1). This representation will be the basis to understand, afterwards, the interrelations created among blocks.

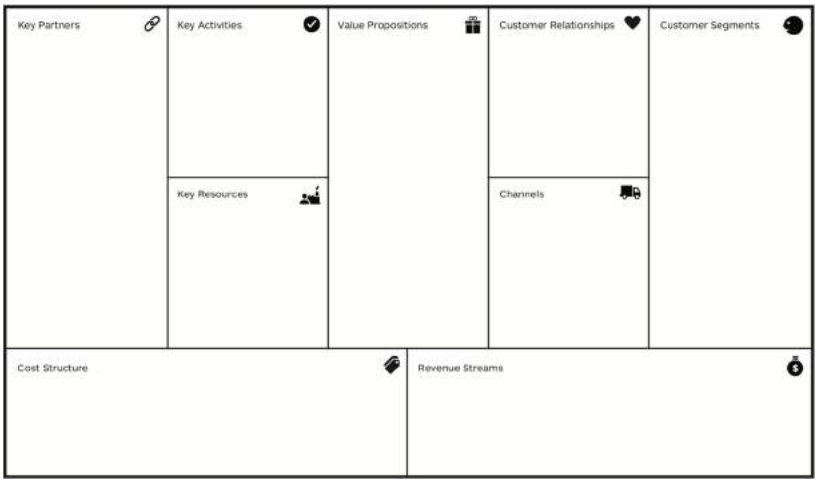

Figure 5.1 Business Model CANVAS. Source: [6]

It is worth noting that the Canvas template splits into two different sides: the value and the cost side. The right side of the Canvas describes the value that the company is delivering to customers. In contrast, the left side identifies how the company manages to create that value with its associated costs.

To better understand the Canvas template's sides, it is necessary to go into further detail in each of the nine building blocks.

5.1.2 Identification of the nine Building Blocks

As aforementioned, the Canvas template is composed of nine building blocks interacting with one another. Down below, you can find the description of each of these blocks:

- **Customer segments (CS):** "*Different groups of people or organizations an enterprise aims to reach and serve*" [6]. It is one of the most critical blocks because the whole Canvas is designed to satisfy customers' needs to make profit. There are different types of customers, among which stand out:
  - **Mass market:** customers present similar needs and problems. Therefore, value propositions, channels, and customer relationships are the same for all the customers.
  - **Segmented:** customers present slightly different needs and challenges, and with that, value propositions, channels, and customer relationships present minor differences for each segment.
  - **Niche market:** the company serves a specific customer segment. For this reason, value propositions, channels, and customer relationships are specifically designed for that customer.
  - **Diversified:** contrary to the mass market, customer segments present entirely different needs and problems. Thus, value propositions, channels, and customer relationships are tailored to each segment.
- **Value proposition (VP):** "*Bundle of products and services that create value for a specific Customer segment*"[6]. Values can be quantitative or qualitative. More specifically, some elements that can contribute to the value creation are: newness, performance, customization, design, brand, price, getting jobs done, cost and risk reduction, accessibility, and usability.
- **Channels (CH):** *"How a company communicates with and reaches its Customer Segments to deliver a Value Proposition"[6].* Thus, this building block is vitally crucial for customer experience. There are two different types of channels, direct and indirect ones (figure 5.2). Also, it can be distinguished between owned channels and partner services.

Figure 5.2 Types of channels. Adapted from [6]

However, what is important are the five different channel phases among which the company can decide where to focus on several or to offer all of them.

1. Awareness 2. Evaluation 3. Purchase 4. Delivery 5. After-Sales

- **Customer relationships (CR):** *"It describes the types of relationships a company established with specific Customer Segments" [6].* There can be found different types of customer relationships, depending on the degree of automation.

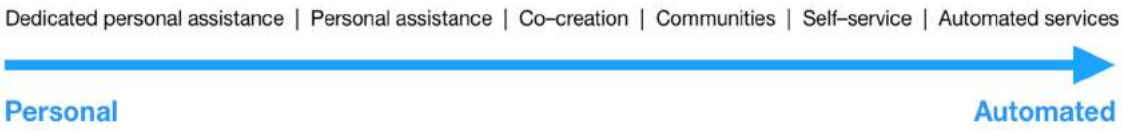

Figure 5.3 Types of customer relationships from personal to automated.

- **Revenue streams (R$):** *"The cash a company generates from each Customer Segment"[6].* There are two types of revenue streams, transaction revenues and recurring ones. However,

what is important to know at this point is how these revenues can be generated by asset sales, usage fees, subscription fees, leasing, licensing, brokerage fees, and advertising.

- **Key resources (KR):** *"The most important assets required to make a business model work"[6].* To create and offer Value Propositions to Customer Segments, each company needs physical, financial, intellectual, and/or human resources.
- **Key activities (KA):** *"The most important actions a company must take to operate successfully[6].* Depending on the main Value propositions, the required key activities can be categorized as: production, problem-solving or platform/network.
- **Key partnerships (KP):** *"The network of suppliers and partners that make the business model work"[6].* A company cannot handle all key resources nor key activities. Thus, they need to establish some key partnerships. There are four types of partnerships: strategic alliances, joint ventures, coopetition, and buyer-supplier relationships.
- **Cost structure (C$):** *"All costs incurred to operate a business model" [6].*

5.1.3 Canvas template

As described above, the Canvas template is formed by nine different building blocks. However, it is worth noting that these blocks do not work in isolation; they are arranged in a way that fits one to another. Following this idea, the template can be divided into two main areas, the value side and the efficiency/cost side, likewise the brain (figure 5.4).

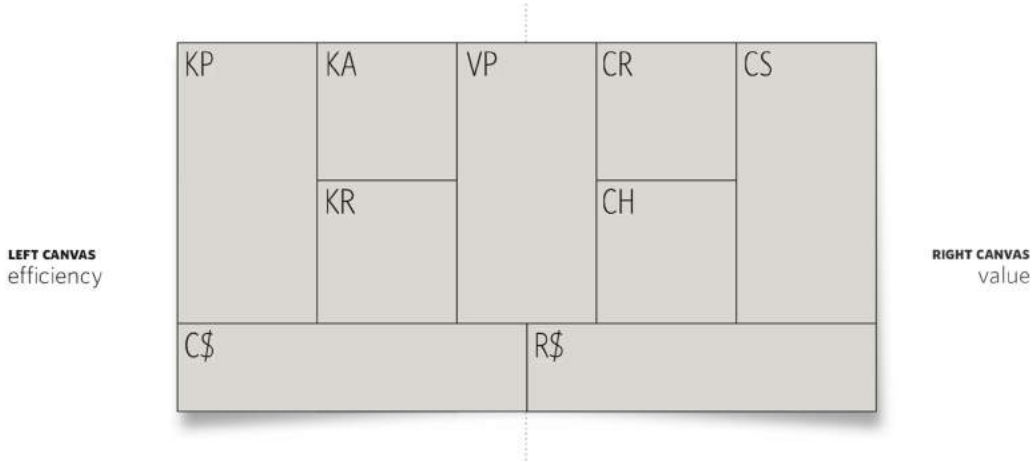

Figure 5.4 Sides of the Canvas Template. Extracted from [6]

By analysing the complete template, we can create a logic story that each company must follow to create their proper Canvas Template.

The story begins with the **Value Proposition Canvas**. Through this technique, a company defines its main value propositions according to the customers that it wants to serve. This methodology consists of listing the gains, pains, and jobs to be done of the different customer segments the company wants to reach. The next step is analysing whether the company offers some products or services able to solve a job to be done, design gain creators for the customer gains or create pain relievers for customers' pains.

Once the company has identified its customer segments and how they are going to create value for each of those customers, businesses have to define how they are going to reach this value to their customers, which **channels** they are going to use to do so. Furthermore, it is quite essential to retain these customers, and it is for that reason that a company has to define some **customer relationships**. For acquiring these values, customers provide some **revenue streams**. However, to create each value proposition, deliver them to the customer and try to retain all customers, the company has to invest in resources that will enable them to develop the key activities needed to manufacture their value. Also, it is crucial to note that no company can provide all **key resources** nor **key activities** by itself. Due to this fact, they have to establish some **key relationships** with other suppliers or investors. Finally, the

development of these activities, resources needed, and established relationships define the **costs** for the company.

To sum up, the Canvas template defines how a company organises itself to create and deliver value. However, to beat the market, it is vital to develop a **strategic analysis** in this aspect where the Feedback Loop Diagram will be decisive.

5.2 The Feedback Loop Diagram

The Feedback loop diagram is a visual representation of a business model developed by J.E. Ricart and R. Casadesus [7]. Contrary to the Canvas template, this methodology tries to represent each business model from a more strategic perspective.

5.2.1 Diagram representation

Its representation is composed of **concepts linked by arrows**. It is important to stand out that not all concepts are presented in the same way. Due to this fact, a legend is needed.

The **choices** are presented in bold and underlined. In contraposition, **consequences** are presented in normal font. However, in order to represent their rigidity, **rigid consequences** are highlighted in a box as we can see in figure 5.5.

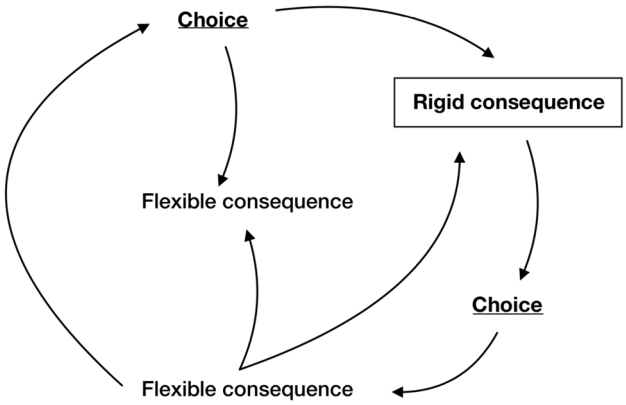

Figure 5.5 Legend for the Causal loop diagram. Adapted from [7]

5.2.2 Definition of the parameters

To be able to understand the representation introduced above and all the cycles that will be created among the whole diagram, first, some theoretical concepts have to be described:

- **Choices:** it refers to each decision that the company takes to define how the enterprise must operate fully. There are three types of choices:
  - **Policy choices**: "it refers to courses of action that the firm adopts for all aspects of its operation" [7].
  - **Asset choices**: "it refers to decisions about tangible resources" [7].
  - **Governance choices**: "it refers to the structure of contractual arrangements that confer decision rights over policies or assets"[7].
- **Consequences:** each choice has a consequence; these consequences can be rigid or flexible.
  - **Flexible**: a consequence is considered flexible when highly dependent on the choices that have generated it [7].
  - **Rigid**: contrary to a flexible consequence, a rigid consequence is not very sensitive to their choices [7].

As mentioned above, the relation among these choices and consequences shape the Feedback loop diagram, the visual representation of a firm's business model.

5.2.3 Feedback Loops

Sometimes, this representation may seem quite complicated. However, the truth is that it might be overpowering when identifying the strengths of the company.

What is important is trying to identify more straightforward cycles inside the whole diagram. These new cycles can be categorised as **virtuous or vicious feedback loops**. Although not being part of the business model itself, they have particular importance when analysing its performance:

- **Virtuous cycles:** *Ricart-Casadesus* define them as “feedback loops that strengthen some components of the model at every iteration” [7]. So, these loops reinforce rigid consequences that may lead to new capabilities and higher competitive advantage of the enterprise.
- **Vicious cycles:** they take place when the virtuous circles are interrupted or reversed and, consequently, they can induce the malfunction of the whole business model[7].

In other words, vicious and virtuous cycles are both feedback loops that strengthen some business model’s components, **the virtuous ones with positive feedback and vicious ones in a negative way**. Due to this fact, it is vitally important to reduce the probability that a virtuous cycle turns into a vicious one. This fact can occur when a feedback loop is interrupted or affected by an external factor. For this reason, it is in this situation when rigid consequences play an important role: the more rigid consequences a business model has, the more difficult is that a virtuous loop turns into a vicious one thanks to the complexity that a rigid consequence becomes modified.

Taking all these ideas into account, it can be concluded that what is essential is to create and feed as much as possible the virtuous cycles and avoid the vicious ones. To achieve that, the business has to establish rigid consequences and take care of them.

With both methodologies introduced, it is vitally important to see how they are used in the market. To do so, some existing business models are deeply analysed to be afterwards able to gather the information needed to see the application of the Canvas template and the Feedback Loop Diagram.

6 Existing Business Models

In the present section, some of the most representative private companies in the Earth Observation sector will be represented by means of a CANVAS business model. Following the CANVAS methodology, the following treats will be presented for each of the studied companies: Customer segments, value proposition, channels, customer relationships, revenue streams, key resources, key activities, key partnerships, and cost structure.

The companies that are going to be studied are: *Planet, DigitalGlobe, Urthecast, Satellogic, Deimos, Spire Global, GomSpace, and Space Flight*. Each of the case studies is related to a more extensive analysis in its respective *Attachment*.

This section aims to present the characteristics of each of the representative companies, so that they might be summarized and studied in Section 7, under the Feedback Loop methodology, and related to proposed **general business traits and behaviours**. Moreover, it ultimately leads to the **success factors** implicit in the success of the Earth Observation companies.

6.1 CANVAS Business Model for *Planet*

Planet is a significantly young company, founded in 2010, based in San Francisco, California. It focuses its value proposition on creating low-cost Small Satellites, which assemble a large Low Earth Orbit constellation. Therefore, the company offers a small period of global Earth coverage, combined with medium to high resolution in images. Besides the image capturing activities, this company also develops tasks in data analysis and geospatial solutions and intelligence development to its customers. The company has been in constant expansion since its foundation.

In the following lines, each of its operating characteristics will be briefly described to develop its CANVAS business model ultimately. Additionally, this case study is attached to ***Appendix A***, where more in-depth analysis and information about the company are presented as a summary of several final theses referenced at the end of the document: [*TFE-1*], [*TFE-2*], [*TFE-3*] and [*TFE-4*].

6.1.1 Customer Segments

Planet possesses a **Segmented Type** of customer segment, meaning that the company is serving a large number of customers, each having slightly different needs. So, all customers require information that can only be provided through satellite imagery. Nevertheless, each customer will require different degrees of processing in the imagery and different kinds of post-developed intelligence from the data to obtain concrete solutions to their problems.

Planet main customers can be mainly grouped into five segments:

- **Engineering and infrastructure data analyst** companies from the private sector.
- **Environmental and agriculture data analyst** companies from the private sector.
- **Non-Governmental Organizations (NGOs)**
- **National and international agencies**
- **Minor customers**: which would include researchers and universities, amongst others.

6.1.2 Value Proposition

It begins with the imagery captured with its three constellations (*PlanetScope, BlackBridge, and TerraBella*). This value proposition is defined as a combination of customized services related to Earth Observation activities.

The Earth Observation data is updated daily and at different resolutions. The access to the imagery and/or pre-processed data is rather easy and cheaper than the traditional competence, allowing nearly

all customers to acquire and extract profit from them. If this is combined with the uniqueness of the service, it creates a great value proposition.

6.1.3 Channels

So that the company might keep constant communication with its customers and vice-versa, it has established robust channels.

Planet, through conferences, reaches the potential clients, exposing which is the product that they are commercializing with. If this proposal attracts the client, the purchase process starts. Depending on the location and size of the client, this process will be done directly (through *Planet*), or indirectly (through intermediates). Afterward, the customer gains access to an online platform, where the purchased imagery is awaiting to be analysed. Finally, if required, the customer may keep in contact with the company to obtain help or provide feedback in the personal development and evolution of the acquired product.

6.1.4 Customer Relationships

It can be said that *Planet* does establish all kinds of relationships; this includes:

- Personal and dedicated personal attention.
- Self-service processes.
- Automated services.
- Communities: it regulates a community where customers might share their experiences and doubts about the imagery.
- Co-creation relationships with key clients. These kinds of relationships simply vary depending on the customers that are being served by providing different assistance to each of the clients, depending on their needs.

6.1.5 Revenue Streams

The company's payment mechanisms are mainly recurring: regular payments are made by each client to keep on having access to the imagery and data provided by Planet. Occasionally, single transactional payments might also be made. Planet's means to generate revenues are the usage and subscription fees and the licensing over its imagery.

6.1.6 Key Resources

They mainly imply:

- **Planet's physical resources:** Compose by its manufacturing facilities, constellations, headquarters, ground station facilities, data storage facilities, and online platforms.
- **Intellectual resources.** The ones that the company trades with. Composed by its licenses and owned imagery.
- **Human resources:** It is formed by all the costs related to the over 150 employees in 2019.
- **Financial resources:** Considering the economic resources related with the investment.

6.1.7 Key Activities

The key activities developed by *Planet* might be sorted into three categories:

- **Those related to production**: the designing, development, and assembly of the current orbiting satellites and constellations; the control of the satellite's orbital positions, the ground monitoring of the constellations, the process of obtaining the captured imagery, the storage processes of this obtained imagery data and the post-processes of data analysis and processing, so that concrete results might be achieved and delivered to each of the customers.
- **Those related to problem-solving**, such as co-creation with partner customers, aim to enlarge the present product offer.
- **Those related to the platform:** Summarized as software development and maintenance activities that keep the delivery platform at optimum conditions. And additionally, the development of an extension of the platform for Planet's analytic missions.

By the end of 2019, *Planet* was also undertaking some activities related to the development of their *Mission 2 phase*; these activities mainly include the development of Artificial Intelligence and Machine Learning methods for the development of a new platform were all objects on Earth are itemized day by day, and the development of mega satellite designs for the observation of the Solar System.

6.1.8 Key Partnerships

Planet has established key partnerships with some strategic companies. Four kinds of partnerships have been established:

- **Strategic Alliances:** with a large number of companies, the company's more concrete products might be developed thanks to some first-hand feedback.
- **Coopetition relationships:** i.e. with *Airbus S&D*, to reduce the risk in starting new projects.
- **Buyer-Supplier relationships**: specially with launchers and material providers.
- **Joint Ventures:** reached with *Google and SpaceX* to start developing the *Mission 2* activities.

6.1.9 Cost Structure

All this efficiency side of the CANVAS reflects in a cost of maintenance, some of the most representative costs that the company needs to deal with are those related to maintenance of assembling facilities, acquisition of machinery and materials for developing the satellites, the recurrent payments for launching the satellites, and the costs related to data storage.

All the ideas previously described are summarized in *Figure 6.1*, and can be better understood after reading ***Appendix A***, which presents *Planet*'s case study, a detailed analysis of the company and its evolution.

It is important to outline that for all the Business Models CANVAS that are presented in this Deliverable, it is used a colour scheme in order to connect the topics and items which are related. Hence, for example, in the following figures all the topics coloured in the same blue range are related.

PLANET

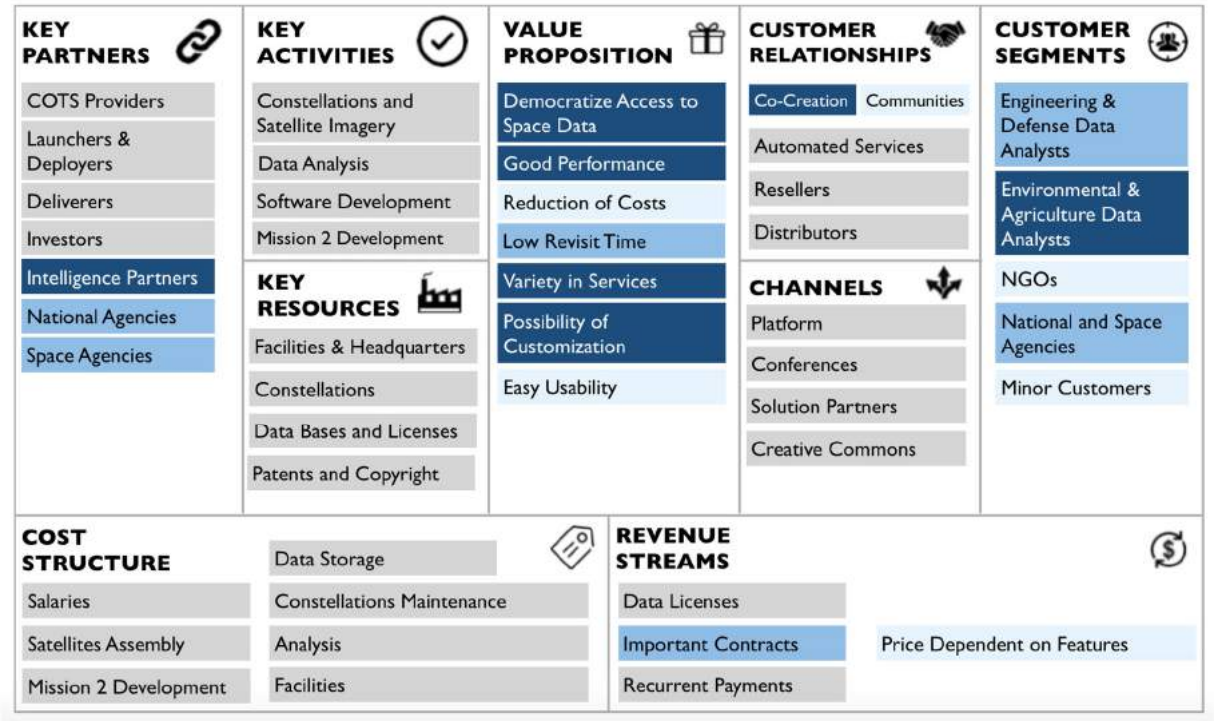

Figure 6.1 CANVAS Business Model for Planet

6.2 CANVAS Business Model for *Digital Globe*

Digital Globe was founded in the 1990s, and it is based in Longmont, Colorado. It is now one of the leaders in the private sector of Earth Observation developing tasks related to image capture, satellite development, and geospatial intelligence development.

In the following lines, each of its operating characteristics will be briefly described to develop its CANVAS business model ultimately. Additionally, this case study is attached to ***Appendix B***, where more in-depth analysis and information about the company are presented as a summary of the final thesis [*TFE-3*].

6.2.1 Customer Segments

Customers that typically use *DigitalGlobe's* imagery and intelligence offer are enterprises specializing in advanced image analysis for consulting services, addressed at different sectors of the industry, such as energy production, infrastructure development, or agriculture production. This set of customers (represented in dark blue in *Figure 6.2*) is interested in high-resolution imagery, as well as the full product offer and product specialization in particular fields. Additionally, *DigitalGlobe* also possesses a set of agreements with the U.S Defense Ministry, through an NGA contract. On a smaller degree, the company commercializes imagery for environmental intelligence.

6.2.2 Value Proposition

DigitalGlobe trades with the value proposition characterized by some general traits, and some specific ones, which make the offer unique. The general ones, shared with other Earth Observation companies are the commercialization of Earth Observation imagery and Earth Observation intelligence data. Nevertheless, what makes this offer unique is that it might be processed so that the final intelligence

results, perfectly adapt to the customer's needs. However, the most distinctive value trait is that the imagery that *DigitalGlobe* provides possesses one of the highest resolutions on the commercial market. In this case, even though revisit time is substantially low, the company prioritizes resolution over periodicity.

6.2.3 Channels

So that the company might keep constant communication with its customers and vice-versa, it has established robust channels.

DigitalGlobe delivers and makes its products accessible through indirect delivery channels, which change depending on the kind of contract that the customer has reached with the company. These channels, mainly are:

- *GBDX Web Platform.*
- *Amazon Cloud Services.*
- *Premium Access DAP.*
- *MAPS API*.

All these channels are owned and operated by the company and aim to grant access to the acquired products through computer-based means easily.

6.2.4 Customer Relationships

In order to reach the customer so that the products are accessible, *DigitalGlobe* presents some different kinds of client-to-company relationships; these relationships might be either direct or indirect, depending on the customers' needs, as well as bi-directional so that information might be exchanged in both ways between customer and company. Additionally, and intending to reach a maximum of customers, *DigitalGlobe* possesses a network of resellers that act as intermediaries. Finally, two extra communication relationships, which imply no direct interaction, might be used: a set of web services and attention through automated services.

6.2.5 Revenue Streams

The payment mechanisms used by the company depend on the kind of contract which has been reached. A significant part of the company's incomes come from the multi-year contracts signed with the *U.S. Government and the NGA*. The rest of the incomes come from the fees related to the acquisition of the imagery products (acquired by private companies related to intelligence and industrial activities), which are either recurrent or dependant on the number of acquired services.

6.2.6 Key Resources

They mainly imply:

- ***P*hysical resources:** Its manufacturing facilities compose its manufacturing facilities, constellations, headquarters, ground station facilities, data storage facilities, and online platforms.
- **Intellectual resources:** The ones that the company trades with; composed by its licenses and owned imagery., as well as an extensive library of satellite imagery, with historical satellite data.
- **Human resources:** Resources applied to the team.
- **Financial resources:** The ones related with the investment.

6.2.7 Key Activities

DigitalGlobe's key activities are related to the satellite assembly and operation activities and the processes of control and image capturing and image and data storage. Once the satellite data has been

acquired, the company develops intelligence-related activities over the raw data, so that the final ready to be delivered product might be obtained. Additionally, the company develops innovation tasks, related to satellite updates as well as software updates.

6.2.8 Key Partnerships

DigitalGlobe has established key partnerships with some strategic companies. Some of the most representative partnerships are the ones displayed in the lines below:

- **National Geospatial Intelligence Agency (NGA):** They present a government-industry partnership through which satellite imagery, captured by *DigitalGlobe* is helping in military operations and civilian healthcare issues, amongst others. The partnership program is the *EnhancedView* program and is supposed to last at least until the end of 2020.
- **Taqnia Space:** Both companies are working together so that the Scout constellation, composed of six small satellites, and manufactured by this Saudi Arabian company, might be launched as soon as possible. The scheduled launch date was supposed to be during 2019, but it has been delayed at least until 2020.
- **SAAB:** Back in 2015, *DigitalGlobe* and SAAB announced a joint venture, called the Vricon Joint Venture to create the globe in 3D. This model would be a photo-realistic 3D model and digital elevation model for enterprise and government geospatial markets, with unmatched coverage and delivery timelines.
- **Timbr:** By the end of 2016, *DigitalGlobe* acquired Timbr, expecting to make it easier to explore the algorithms developed by their GBDX ecosystem and data partners, and accelerating the creation of new customer solutions. Timbr, a data science company, was supposed to provide new technologies and expertise to improve the usability and accessibility of the GBDX platform, allowing more customers to derive valuable insights about *DigitalGlobe's* satellite imagery.
- **Radiant Spatial Energy:** Back in 2014, *DigitalGlobe* acquired Spatial Energy, a leading source for digital imagery and related services to the energy industry.

6.2.9 Cost Structure

All this efficiency side of the CANVAS reflects in the cost of maintenance. Some of the most representative costs that the company needs to deal with are those related to:

- Maintenance of assembling facilities
- Acquisition of machinery and materials for developing the satellites
- Recurrent payments for launching satellites
- Data storage and analysis
- Scout satellites development and updates that have to be made to the already orbiting constellations.

All the ideas previously described are summarized in *Figure 6.2*, and can be better understood after reading ***Appendix B***, which presents *Digital Globe's* case study, a detailed analysis of the company and its evolution.

DIGITALGLOBE

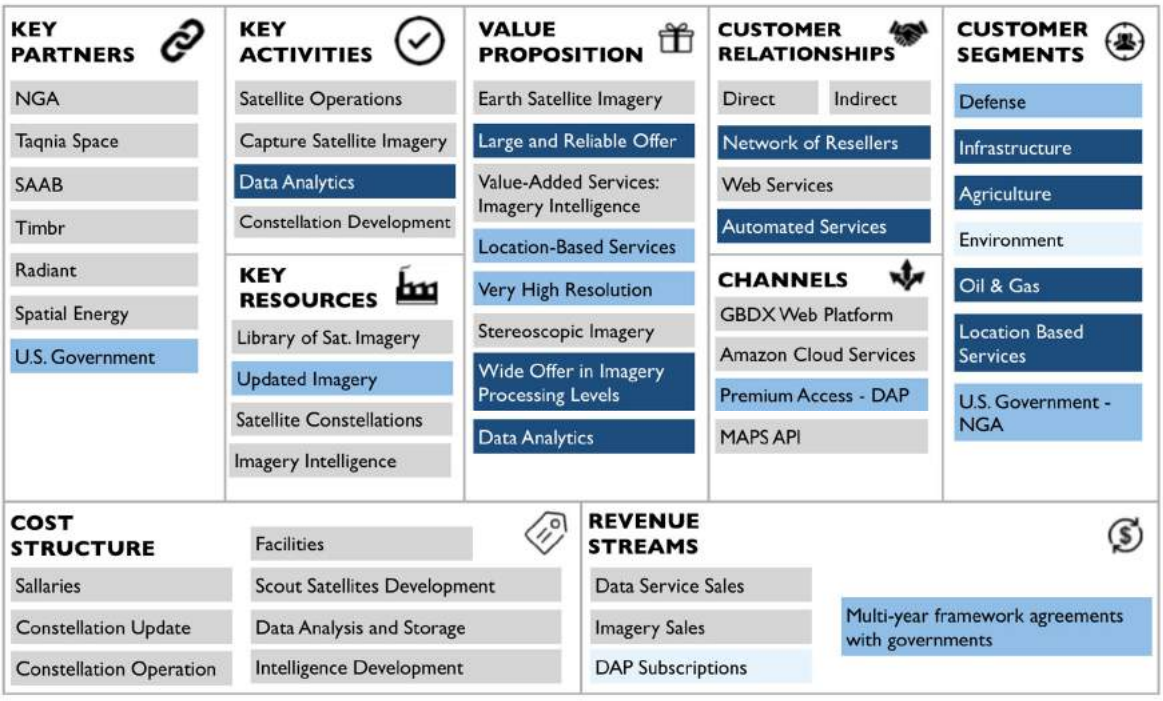

Figure 6.2 CANVAS Business Model for Digital Globe

6.3 CANVAS Business Model for *UrtheCast*

UrhteCast was founded in 2009, and it is based in Vancouver, Canada. The company is a satellite, imaging, and geoanalytics developer company. It tracks long-term trends, monitors shorter-term changes, and provides intelligence about guided, strategic actions to fulfill required missions.

In the following lines, each of its operating characteristics will be briefly described, with the aim of ultimately develop its CANVAS business model. Additionally, this case study is attached to ***Appendix C***, where more in-depth analysis and information about the company are presented as a summary of the student's final thesis [*TFE-5*].

6.3.1 Customer Segments

UrtheCats possess a **Segmented Type** of customer segments, all accessing the same Earth satellite imagery, yet each with slightly different needs. In other words, all customers require information that can only be provided through satellite imagery. Nevertheless, each customer will require different degrees of processing in the imagery and different kinds of post-developed intelligence from the data to obtain concrete solutions to their problems.

The primary customer segment groups might be divided into three, which at the same time have subgroups:

- Government Institutions: This would imply national governments, defence ministries, and activities related to defence, such as borders and maritime surveillance. These kinds of customers are interested in being provided with high-resolution imagery as well as small revisit times.

- Private Companies. Notably, companies related to infrastructure and engineering intelligence, natural resources monitoring, and disaster management. These companies would be more interested in obtaining imagery on a broad spectrum of possibilities and vast areas at once.
- Streaming Platforms: Economically, this is the weakest customer segment; however, taking profit of the cost reduction in reaching space-related products, they might as well be a customer to keep in mind.

6.3.2 Value Proposition

Through its Iris and Theia cameras, located on the Russian Module of the International Space Station, and its fleet of orbiting satellites, *UrtheCast's* value proposition is characterized by delivering a wide offer of Earth Satellite Imagery which is easily accessible. This imagery is available in different band spectrum, resolutions, and even as an UHD Video. Additionally, the value proposition has a high degree of customization and also offers access to an archive of Earth Imagery, which had been captured by a previous image capturing tasks from the orbiting satellites.

6.3.3 Channels

In order to make the products accessible to the customers, UrtheCast owns a series of delivery channels. The company disposes of Direct Communication Channels in a bidirectional way so that communication between customers and the company might be kept. Once the communication has been established, products are delivered through an owned *API platform or GeoTIFF Data*.

6.3.4 Customer Relationships

The relationships that *UrtheCast* maintains with its customers are either direct, through traditional meetings, when the customer requires it, or, in most of the cases, indirect. To make the communication more fluid and secure, the company also disposes of automated means.

6.3.5 Revenue Streams

In order to sustain the entire company, *UrtheCast* owns some revenue streams. They mainly come from the following activities:

- **High Resolution Images Sales:** The main customers that make use of this kind of product are the government and government-related enterprises. At a minor degree, some intelligence companies also acquire this kind of product.
- **Mid Resolution Images Sales:** Mainly acquired by the private company customer segment.
- **API Subscription**: Recurrent payment.

6.3.6 Key Resources

UrtheCast's key resources are represented by the ones presented in the following lines:

- ***P*hysical resources**. Composed by its operations centre, its *DEIMOS-1 and DEIMOS-2* satellites, the Iris and the Theia cameras, located on the ISS, and its network of ground stations.
- **Intellectual resources.** They are composed of its licenses and owned imagery and an extensive library of satellite imagery, with historical satellite data and its API platform.
- **Human resources:** Resources applied to the team.
- **Financial resources:** Those related with the investment.

6.3.7 Key Activities

The company's key activities are those related to satellite operations (from satellite control, monitor, to design and assembly), those related to image and video obtainment, including data capturing,

downlinking and storage, and those related to image intelligence development, which consists on transforming the raw imagery data into sellable and valuable data intelligence.

6.3.8 Key Partnerships

UrtheCast counts on a series of key partnerships so that its activities might be successfully undertaken to keep on expanding. *Figure 6.3* displays the primary key partnerships that *UrtheCast* possesses nowadays, and they are all explained in detail in section 4 from ***Appendix C***. The most important partnerships that sustain the *UrtheCast's* operations are those established with *Roscosmos, RSC Energia, Rutherford Appleton Labs, and MDA Corporation*.

6.3.9 Cost Structure

All this efficiency side of the CANVAS reflects in a cost of maintenance, some of the most representative costs that the company needs to deal with are those related to the satellite and cameras maintenance, as well as the new satellite design and assembly tasks, or those related to maintaining the ground station network. An essential part of the costs also goes to the data storage and analysis tasks, and the maintenance of the API software.

All the ideas previously described are summarized in *Figure 6.3*, and can be better understood after reading ***Appendix C***, which presents *UrtheCast*'s case study, a detailed analysis of the company and its evolution.

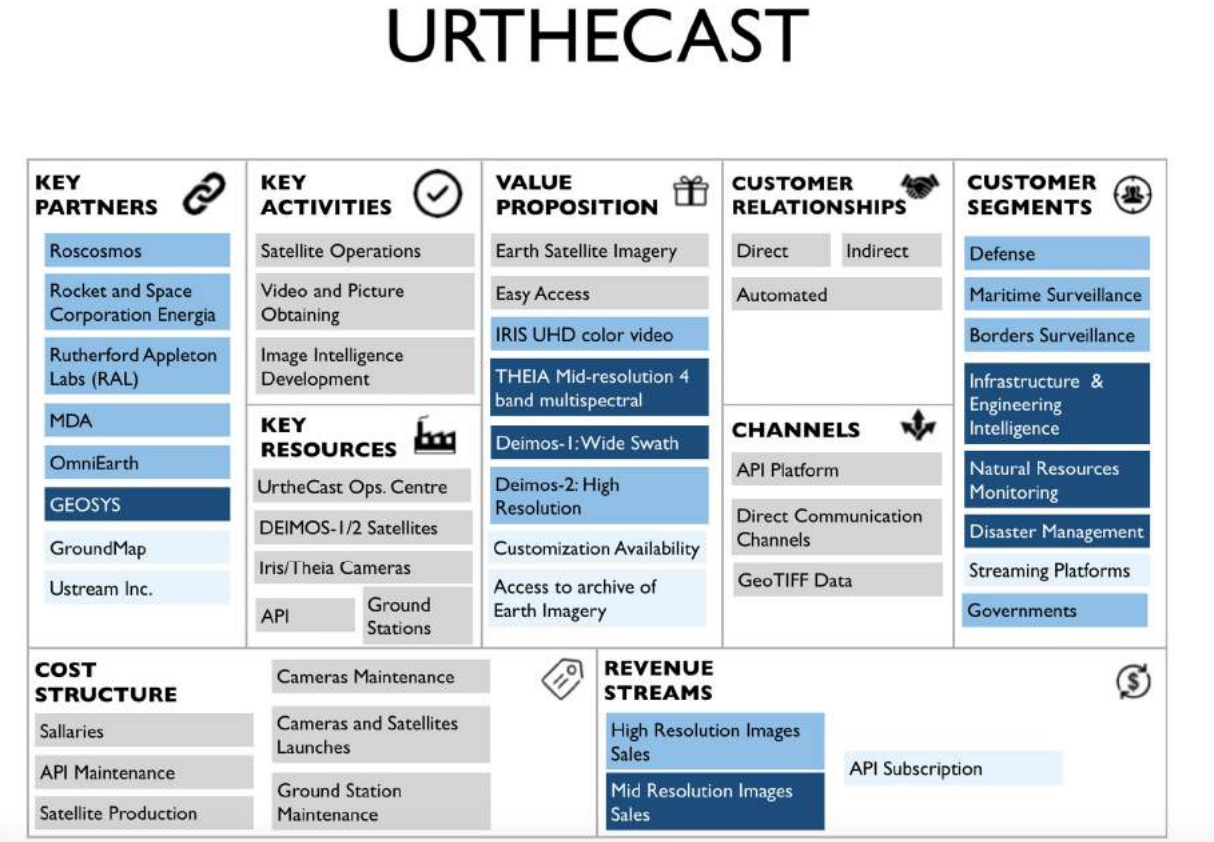

Figure 6.3 CANVAS Business Model for UrtheCast

6.4 CANVAS Business Model for *Satellogic*

Satellogic was founded in 2010, and it is based in Buenos Aires, Argentina. *Satellogic* is the first vertically integrated geospatial analytics company, and they develop tasks related to satellite design and assembling, AI expertise or geospatial intelligence and solutions provident.

In the following lines, each of its operating characteristics will be briefly described, with the aim of ultimately develop its CANVAS business model. Additionally, this case study is attached to ***Appendix D***, where more in-depth analysis and information about the company are presented as a summary of [*TFE-5*].

6.4.1 Customer Segments

Satellogic, as a relatively newly created company, at the moment, does not possess a strong network of customers yet. However, its products have been created, keeping in mind the kind of target they are aiming to. Therefore, it can be said that the company is aiming to possess a **Segmented Type** of customer segments. It means that *Satellogic* is actively looking for serving a large number of customers which base their activities in a large number of similar yet different needs. These different needs will be satisfied by applying different ways of processing the Earth data imagery.

The leading Customer groups that *Satellogic* is focusing its attention to are presented in the following lines:

- **Environment and Agriculture:** By targeting natural resources monitoring, they aim to present analysis and concrete results in these fields. This information is susceptible to be used either by individual farmers as well as Governments.
- **Energy:** Both for energy production as well as energy distribution.
- **Disaster Response:** Increasing the reaction capacity and reducing the time for responding a natural disaster, among other possible issues.
- **Security:** Developing new technology for increasing the national security, although it can be applied for individual targets too.
- **Infrastructures and Engineering Intelligence:** Development of new software technologies applied in this area.
- **Non-profitable means:** Humanitarian and scientific free distribution.

6.4.2 Value Proposition

When exposing *Satellogic's* value proposition, it has to start by clarifying that it is in its process of being fully developed and operative. Up to the moment, *Satellogic* operates a small constellation of eight satellites, through which they have started obtaining high-resolution and specific kinds of Earth Imagery. Down on Earth, they have also been developing data analysis means to develop the added value services related to this imagery.

Keeping an eye on the future, their value proposition aims to offer Earth imagery at both low prices and very small revisit time (the company claims that it might be reduced to five minutes between image and image). At the same time, this imagery will have a wide range of resolution (from low to high), will be processed so that it might be used in a large number of investigation fields (regarding the customer segments that might use this imagery), and will be easily acquirable at low prices.

6.4.3 Channels

The company possesses the usual communication channels with its customers, which means that communication is mainly direct, between company and customer, through a communications salesforce. Since the company is still under development, it could be expected that their communication channels will expand and refine. These will potentially translate into the development of more communication services which are automatic-based, and with an expansion in the resellers and intermediates networks.

When it comes to the delivery of images and results, by now, apart from direct channels, *Satellogic* is also able to deliver via *Azure*, an online data analytic platform, thanks to the *Microsoft* partnership contract.

6.4.4 Customer Relationships

In a similar way to what happened with the communication channels, since *Satellogic* has not fully started its commercial activity, regarding the full commercialization of its imagery products, the customer relationships cannot still be completely profiled. At present, relationships are mainly direct, which implies that the customers receive the personal and dedicated personal attention and might have a certain degree of co-creation relationship when it comes to obtaining the required product.

6.4.5 Revenue Streams

Satellogic possesses two main ways of obtaining revenues through the commercialization of its imagery and data services (leaving the incomes that come from the investment rounds apart). These two ways are the recurring payments received through its subscription fees and the single payments which correspond to a kind of pay-per-picture payment.

6.4.6 Key Resources

They mainly imply:

- **Physical Resources:** Up to the end of 2018, this would be eight orbiting satellites, two ground stations, the Buenos Aires headquarters, and the Montevideo manufacturing facilities. By 2020, these physical resources are expected to increase, reaching a fleet of 300 orbiting satellites, increasing the number of owned ground stations, and potentially acquiring new facilities as well.
- **Intellectual Resources:** They are composed of the Earth Observation imagery obtained, the derived data and intelligence from the imagery, and the designs of the owned satellites and the data analysis software, amongst others.
- **Human Resources**: Its teams of employees composed them.
- **Financial Resources:** Which includes, amongst others, the funds obtained after the investment rounds.

6.4.7 Key Activities

The key activities developed by *Satellogic* imply an extensive list of activities since the company has chosen to develop all kinds of activities regarding satellite design and manufacturing, data analysis software development, satellite operation, and intelligence development on its own. All of this reflects the Lean Manufacturing philosophy with which they operate.

6.4.8 Key Partnerships

Up to 2018, *Satellogic* was collaborating with the *National Atomic Energy Commission*, the company *INVAP*, which assisted in the manufacturing process of the first launched satellites, *Microsoft Azure*, which, through a contract, provided services related to data storage and analysis, and on a smaller scale, with the scientific community, which received open-sourced software and imagery from the company, and which was expected to return scientific knowledge and conclusions about them.

Regarding the future of the company's partnerships, they have actively stated that they count on establishing key partnerships in the ground operation areas.

6.4.9 Cost Structure

Some of the most representative costs that the company has to face are those related to satellite design and assembly. These costs will decrease its value once the 300 satellite constellation is operative, however, since the expected lifetime of the satellites is of around two to three years, the constellation will have to be constantly renewed, hence, some fixed costs regarding satellite manufacturing will remain.

The other most representative costs are those related to software development. This software is the one that will transform the raw data obtained from the satellite's imagery into value-added products, ready to be commercialized.

All the ideas previously described are summarized in *Figure 6.4*, and can be better understood after reading ***Appendix D***, which presents *Satellogic's* case study, a detailed analysis of the company and its evolution.

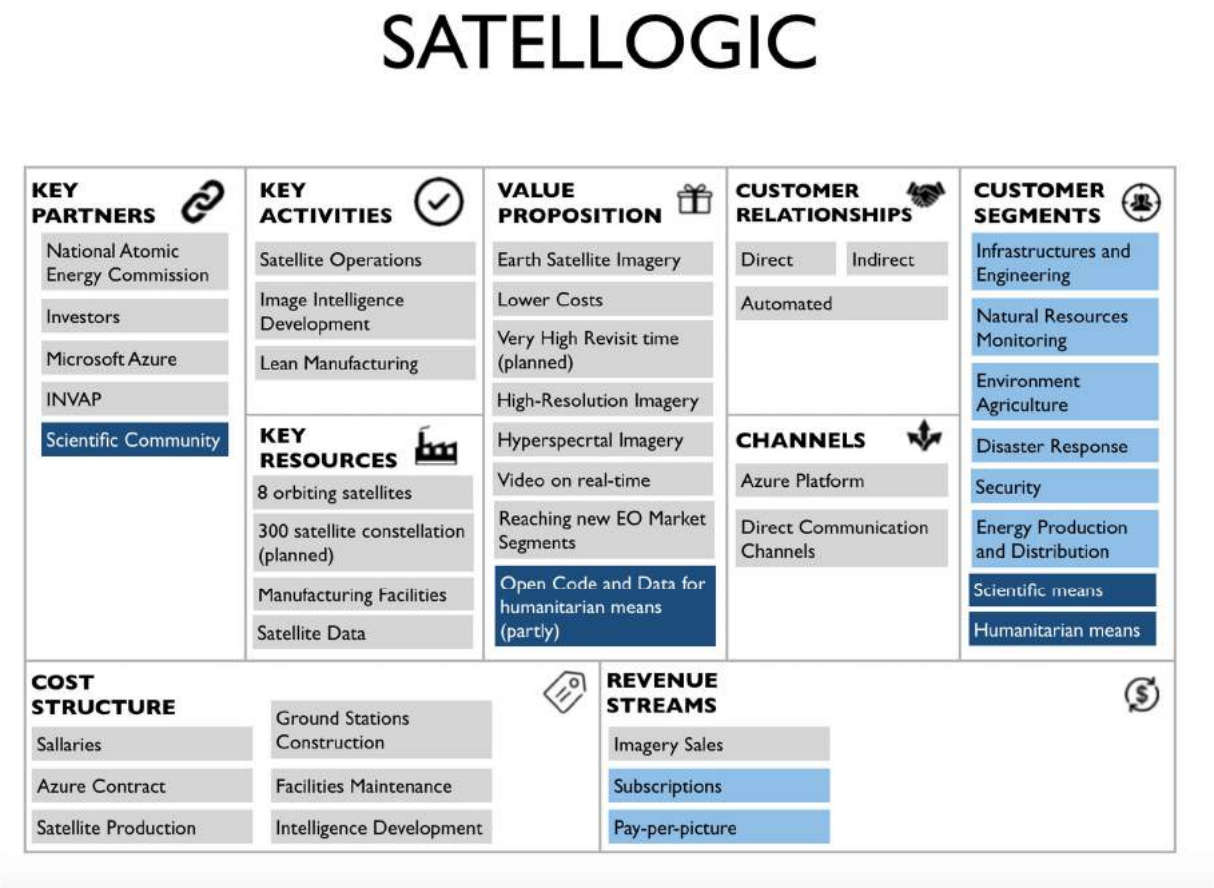

Figure 6.4 CANVAS Business Model for Satellogic

6.5 CANVAS Business Model for *Deimos*

Elecnor Deimos was founded in 2001, aiming to develop and provide high-tech systems and engineering solutions. Based in Tres Cantos, Spain, this company is the technology branch of *Elecnor,* one of the leading Spanish companies in engineering, infrastructure and construction projects, and a prominent investor in renewable energy, environmental infrastructure, and space.

In the following lines, each of its operating characteristics will be briefly described, with the aim of ultimately develop its CANVAS business model. Additionally, this case study is attached to ***Appendix***

E, where more in-depth analysis and information about the company are presented as a summary of [*TFE-6*].

6.5.1 Customer Segments

The customer segments that *Deimos* is currently serving are mainly ten, schematically presented in *Figure 6.5* and explained in the following list:

- ***UrtheCast*****,** which in 2015 purchased the satellite *Deimos-2,* still operated by *Deimos Imaging.*
- ***ESA and NASA:*** With which *Deimos* collaborates in various programmes, providing multiple solutions depending on the mission's parameters.
- **Deimos Imaging:** Currently subsidiary of UrtheCast.
- ***Open tenders:*** An example would be the leadership that was granted by the Ministry of Spain within the European Union in the Neptuno project.
- ***SATRECi:*** Based on the flight segment.
- ***DMS:*** Regarding the ground segment software.
- ***VERTEX:*** An antenna manufacturer.
- ***KOSMOTRAS:*** Based on the launch segment.
- ***Elecnor Group:*** Security and multiservice network.
- ***Spanish Government:*** Regarding the mining funds.

Besides this, *Deimos* is also providing intelligence in more extensive areas regarding its customer segments, such as agriculture, defence, or disaster monitoring, which might be better assessed through *Figure 6.5*.

6.5.2 Value Proposition

The value proposition that *Deimos* is offering is focused on the following areas of activity:

- **Space Consultancy:** It mainly specializes in the feasibility of any satellite in technological and business teams.
- **Data Reception and Distribution:** The company owns three antennas for satellite monitoring to third parties.
- **Data reseller:** Satellite or other kinds of data.
- **Hardware and software developer:** Related with research and development of a new technology.
- **Ground Information Systems (GIS):** As well as provider of other downstream services.
- **Value-Added Services (VAS).**

Its value proposition is complemented by a series of services related to satellite monitoring, mission planning, data storage, and processing integrated into its *Gs4EO* suite of services. All these services characterize the value proposition as broad, efficient, and reliable in all areas related to Earth Observation activities, from upstream to midstream and downstream.

6.5.3 Channels

To communicate with its potential customers, the company possesses a series of direct and indirect channels. The direct channels imply personal contact, as well as telephone contact. The indirect channels are related to its website and social media. When it comes to delivery channels, part of the services used in the *Gs4EO* suite are used. These services would be, concretely, the *USER4EO* services.

6.5.4 Customer Relationships

When it comes to the relationships which are established between company and customer, it is worth mentioning that after-sales services are offered; since some of the services which are commercialized

require the aid of the company to be used. Apart from this, *Deimos* also aims to have feedback from clients in order to improve products.

6.5.5 Revenue Streams

Regarding the company's revenue streams, the selling of the price and price strategy is confidential; nevertheless, the revenue streams come from the sales and renting of the following services:

- Hosting of antennas.
- Data Selling.
- Satellites development, integration and operation.
- 4EO suite of product licensing.
- Imagery selling.
- Feasibility and risk assessments.

6.5.6 Key Resources

The resources that the company possesses in order to develop its Key activities, which will be explained in the following lines, are characterized by the following groups:

- **Financial Resources:** *Elecnor Group* funds, public space agencies programmes, European open tenders, and internal assets.
- **Physical Resources:** Subsidiaries in five countries, ground system facilities, and physically developed technology.
- **Technology Resources:** Facilities IT-controlled, antennas for satellite surveillance, Gs4EO suite of products and services, a business strategy based on diversification, space technology knowledge.
- **Human Resources:** Highly qualified staff.

6.5.7 Key Activities

The key activities that the company needs to develop in order to be able to provide the value proposition to its customers are those related to the space consultancy projects, the data related activities, such as data obtaining, storage and processing, in order to commercialize these products; the hardware and software development to be sold to third parties, and the development and commercialization of the 4EO suite products.

6.5.8 Key Partnerships

To develop the key activities that the company needs to perform so that the value proposition might be developed, *Deimos* counts with the following key partners:

- ***GUDNUS:*** company that provides efficient solutions for energy engineering projects. Its partnership is addressed to provide thermography services by using a self-developed tool developed in the project *APPIDE*.
- ***ORBEX:*** company that develops an innovative launch vehicle for small satellites called Prime. Deimos Space has become an investor of *Orbex* for the partnership for satellite launches.
- ***ESA:*** European Space Agency, a public agency that carries out missions into their different space programmes.
- ***Mars Sample Return:*** this is a project carried out in collaboration by ESA and NASA, which is addressed to bring to the Earth different samples of Mars. In this project, there are many partners involved, such as *Thales Alenia Space, GMV, OHB, and Deimos Space*, apart from the public agencies.
- ***Neptuno Project:*** project for the CDTI (from the Spanish *Centro para el Desarrollo Tecnológico Industrial*) within the European Union that faces the main challenges of maritime surveillance.

- ***Dauria Aerospace:*** its partnership is aimed to develop *Deimos Perseus*, which will be the first satellite constellation to provide frequent images of the entire Earth.
- ***Mohammed Bin Rashid Space Center (MBRSP):*** partnership funded by the International Partnerships in Space Programme from the *UK Space Agency* to automate the geospatial information that will feed the initiative *Smart Dubai* will help to plan and monitor the urban transformation. All this within the *SAFIY* project.

6.5.9 Cost Structure

The company must face the cost structure so that the projects might be undertaken mainly characterized by the activities listed in the lines below:

- Highly qualified staff.
- Significant investment in R&D.
- Infrastructure related costs.
- Marketing and sales-related costs.
- Raw material acquisition costs.
- Logistics related costs.

All the ideas previously described are summarized in *Figure 6.5* and can be better understood after reading ***Appendix E***, which presents the *Deimo*s case study, a detailed analysis of the company, and its evolution.

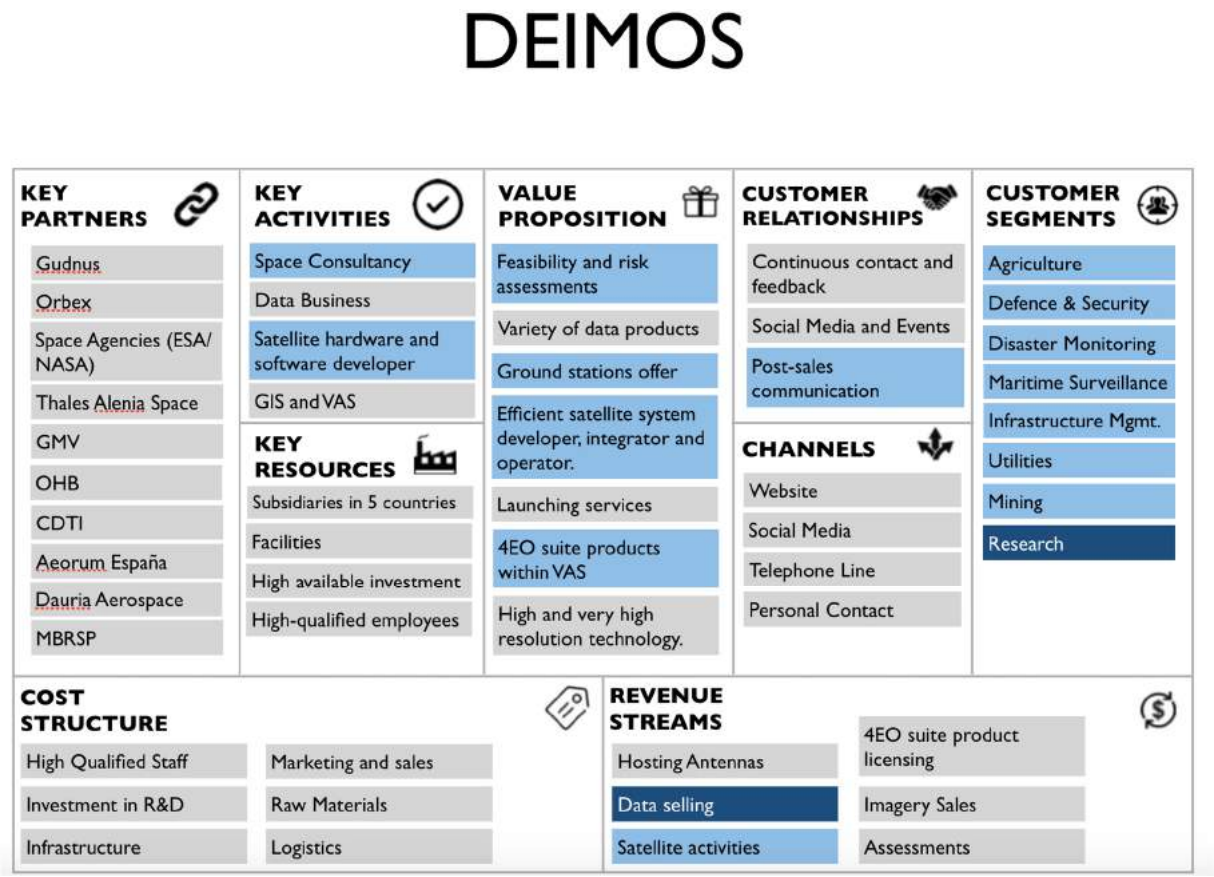

Figure 6.5 CANVAS Business Model for Deimos

6.6 CANVAS Business Model for *Spire Global*

Spire Global was founded in 2012, and it is based in San Francisco, California. It provides the most advanced aviation, maritime, and weather tracking in the World through satellite data algorithms. All of this is possible thanks to a wholly-owned and a developed constellation of Nanosatellites, a global ground station network, and continuous operations that bring real-time Earth coverage.

In the following lines, each of its operating characteristics will be briefly described, with the aim of ultimately develop its CANVAS business model. Additionally, this case study is attached to ***Appendix F***, where more in-depth analysis and information about the company are presented as a summary of the thesis [*TFE-7*].

6.6.1 Customer Segments

Spire's customer segments might be firstly divided into those customers who make use of the satellite imagery for aerospace purposes, those customers who are in the maritime sector, and a final group that is not in any of the two previous groups. Considering each of the groups:

- **Aerospace Sector:** This includes the governments, which make use of satellite data, the air traffic control companies, those companies which monitor the weather from space, and those used linked to the aerospace defence. This sector is interested in high-quality imagery, which might be continuously updated, and which might cover any area of the entire World.
- **Maritime Sector:** These sectors make use of the daily updates of the company's satellite imagery to locate ships in open waters and control the maritime ways.
- **Investigation Sector:** This last vital sector is the least economically representative; however, it makes use of the imagery and data that Spire can provide, in order to create intelligence from it and innovate, through data science, in different fields.

6.6.2 Value Proposition

Spire Global sustains its value proposition on three main pillars that improve the Earth Observation market by using customizable software and multifunctional sensors to adapt to customer requests and choosing quantity oversize by:

- Offering continuous coverage of any place on Earth and taking advantage of their location in LEO.
- Leading customers to use low-cost devices.
- Having responsible treatment of space debris by using smallsats.

Spire Global also aims to become an inspiration and a leader in the Earth Observation business by using LEO orbits and developing new technologies and solutions to further explore in this newly emerging sector.

6.6.3 Channels

The firm's ways to get in touch with their customers are mainly online-based using an owned web page, where anyone can get information about the values and services that the company offers. Additionally, the company also does broadcast through social media and allows those who are more interested in the firm and its signs of progress to request news via email subscription to their blog. To deliver the products to the customers, the company possesses a suite of GIS products and an owned API platform.

6.6.4 Customer Relationships

Spire Global makes excellent efforts to provide a transparent image to its customers, offering and sharing as much information as they can, trying to give a close relation through news or online chats, amongst others. Moreover, the company had to offer, at the moment only to the maritime sector, but

perspectives point towards expanding to other sectors, the Developer Portal, an online space where customers might develop their own AIS projects with cloud-based APIs.

6.6.5 Revenue Streams

The revenue streams that the company possesses in order to sustain the entire structure is represented by the incomes which come from the EO studies which it delivers, which mainly are sold to the investigation sector; the meteorology and the air traffic data, which are sold to different aerospace companies, as well as the maritime Earth observation data, sold to the maritime sector. All of these products might be sold to any of the customer segments, so the company can make an extra profit of commercializing the EO imagery.

6.6.6 Key Resources

Human resources and supplies to assemble the small satellites, and maintain an appropriate degree of production activities are essential. As the lifetime of the performed missions is significantly short, compared with traditional satellite lifetimes, a larger number of satellites need to be assembled, so the number of orbiting devices in missions remains constant. Additionally, ground stations that allow constant tracking and data collecting are essential.

6.6.7 Key Activities

The company is trying to become a leader in the technology innovation field; therefore, the development and investigation which concerns the small satellites is an essential activity to improve the efficiency of their operations and services. The maintenance of these devices and the servers to keep safe data storage is also vital. Lastly, the transformation of this obtained data into a more valuable product, related to data intelligence, is another of the key activities developed by the company.

6.6.8 Key Partnerships

In order to complete the information treatment, it is indispensable to collaborate with the sectors, which are specified in this block in Figure 6.6. These three main sectors are also the principal customer segments, which give Spire Global the necessary information to accomplish the studies added to the information collected from orbit. Usually, the relationship between these customers and the firm is managed from governments that comprehend these three sectors in a particular country, so they are considered partners. In the aerospace sector, partnerships with *Ball Aerospace* and the *NGA* are considered of high importance, in the meteorological sector, it is the *NOAA* partnership, finally, in the data storage field, the partnership with *Amazon Cloud* based services is of great importance as well.

6.6.9 Cost Structure

The main costs of this company are the contracts that allow it to include these small satellites into large launchers and the human costs and the infrastructure costs to complete the firm's key activities.

All the ideas previously described are summarized in *Figure 6.6*, and can be better understood after reading ***Appendix F***, which presents *Spire Global* case study, a detailed analysis of the company and its evolution.

SPIRE GLOBAL

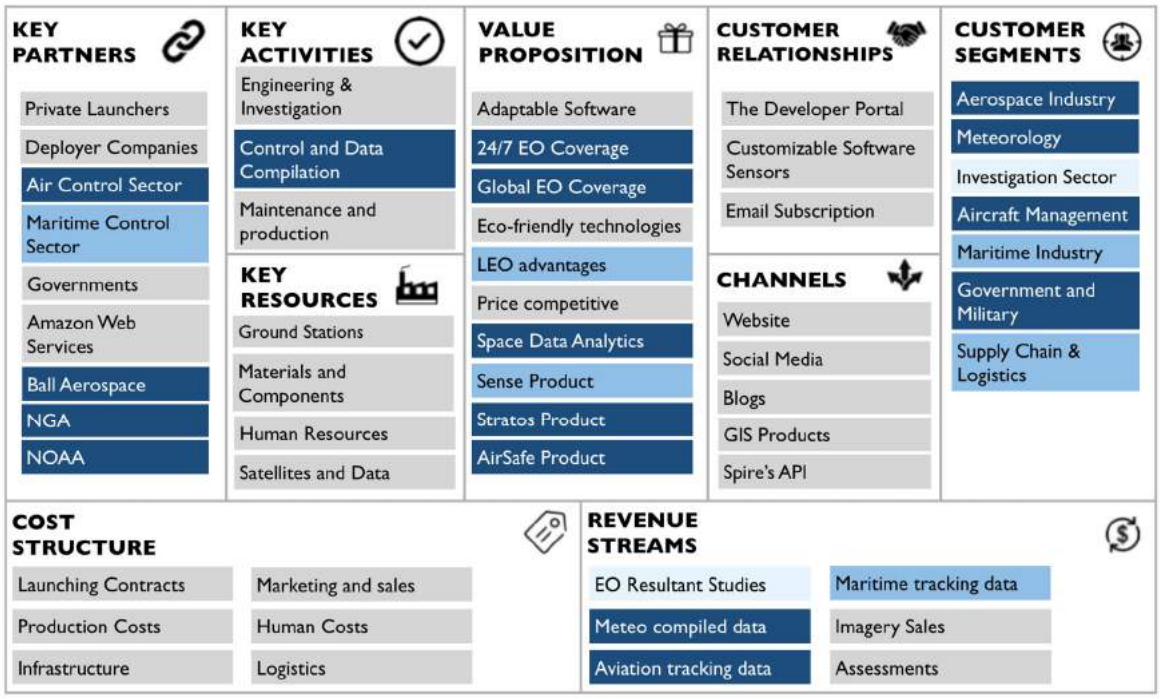

Figure 6.6 CANVAS Business Model for Spire Global

6.7 CANVAS Business Model for *GOMSpace*

GOMSpace was founded in 2007, and it is based in San Francisco, California. With the parent company now being *GomSpace Group AB*, it provides turn-key solutions for space-based business, developing and commercializing off-the-shelf payloads and platforms in the nanosatellites sector. Based in advanced radio technology, *GomSpace* solutions include the Internet of Things (IoT), communications, tracking, surveillance, and remote sensing.

In the following lines, each of its operating characteristics will be briefly described, with the aim of ultimately develop its CANVAS business model. Additionally, this case study is attached to ***Appendix G***. More in-depth analysis and information about the company are presented as a summary of the thesis [*TFE-7*] and [*TFE-8*].

6.7.1 Customer Segments

The more significant customer segments that the company serves are the National and Private Spaces agencies, followed by the military defence industries. The sector oriented to University investigation, as well as general scientific investigation, is also representative. The last sector that the company offers services to is private companies. The company self-defines its customer segments as *Science, Academia, Commercial and Defence*; however, more subgroups have been decided to be significative enough as to be displayed in *Figure 6.7*.

6.7.2 Value Proposition

GomSpace offers devices, as well as services. Their devices have multiple options of modular plug-&-play accessories such as propulsion, communication, and control systems from an operational point of view, and the possibility of selecting the mission payload with its modules. *GomSpace* offers custom-

made devices and services to enhance the exploitation and endurance of the missions. These services are oriented to take place in large operations; therefore, they are considered to be related to the previously presented customer segments. Besides the focus of its operations, the customization of missions, the proposals related to space data analytics, the Internet of Things, and the communications and remote sensing are remarkable.

6.7.3 Channels

GomSpace owns a network of communication channels, represented by its web page and social media, through which the customers can keep up with the company's news, developments, and announcements. Additionally, to cover the larger and more important missions, *GomSpace* owns a net of headquarters around the World, which gives full coverage and assistance to this sort of customer.

6.7.4 Customer Relationships

GomSpace customers can directly communicate with the company to get specialized devices and solutions, or to request information on their mission's status. This Direct relationship might go one step beyond, allowing the customer to work with the company to co-create its concrete product or service. Lastly, the company also offers the possibility of relating to them through indirect means, such as through email.

6.7.5 Revenue Streams

Revenue Streams are mainly represented by the sales of the customized devices, as well as fees coming from the development of these devices. Other revenue streams come from the sales of satellite-related services, including the EO data imagery, the renting of the satellite platforms, or the fees from the constellation management services.

6.7.6 Key Resources

In order to correctly perform all the key activities, *GomSpace* needs to keep a certain level of material and resources, as well as qualified personnel to craft the nanosatellites and more specialized employees to develop the activities related to the MCOP operations and updates. Headquarters and facilities around the World are also fundamental. Nevertheless, the company has been opening offices all around the world to allow its expansion and evolution.

6.7.7 Key Activities

As the company offers the crafting of nanosatellites, engineering and investigation are primordial. Moreover, both the constant maintenance of MCOP network and the enhancement of its services is vital to keep this service as a differentiation of the firm. Related to this issue, as the company uses the conventional commercial ground stations to establish this connection, keeping this compatibility is essential, contrarily, the entire MCOP device would need from another solution.

6.7.8 Key Partnerships

As GomSpace aims to reach missions which lead the company to innovate and improve the offered products, since the beginning, the company has put efforts into establishing relationships with agencies and large sectors of investigation fields, which, as partners were interested in applying the technology of the nanosatellites into the success of their missions. An example of this behaviour would be the *GOMX-3*, a satellite launched in October 2015, in collaboration with ESA; this mission was a success from the perspective of performance and EO applications using novel technologies as X-band downlink. Other significant partnerships have been those established with the *Ministry of Economy of Luxembourg*, or the *AISTECH* and *Sky and Space Global* partnerships, in the launching fields.

6.7.9 Cost Structure

The development of the key activities, both maintenance, and improvement of the MCOP and the crafting of the devices, would have a cost associated. As the company became larger, its workforce had to become more extensive as well. Additionally, the number of offices and headquarters around the world was also enlarged in order to face the increasing demand. These changes translated into an increase in the cost structure of the company.

All the ideas previously described are summarized in *Figure 6.7*, and can be better understood after reading ***Appendix G***, which presents *GOMSpace* case study, a detailed analysis of the company and its evolution.

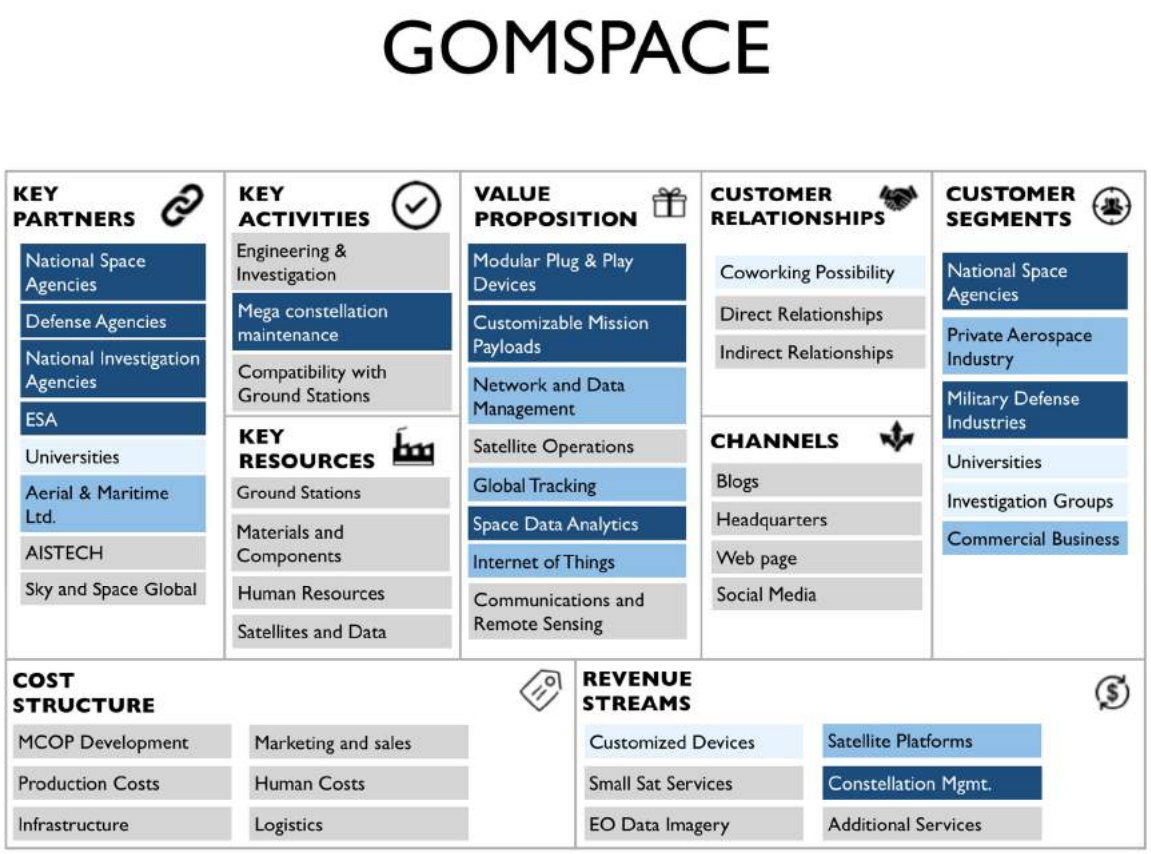

Figure 6.7 CANVAS Business Model for GOMSpace

6.8 CANVAS Business Model for *Spaceflight*

Spaceflight Industries is composed of four main branches within its internal structure. Each of these branches could be analysed as separate companies since they develop different activities and target different customer segments. However, it has been considered to be of interest to the study of the entire structure of *Spaceflight.*

In the following lines, each of its operating characteristics will be briefly described, with the aim of ultimately develop its CANVAS business model. Additionally, this case study is attached to ***Appendix H***, where more in-depth analysis and information about the company are presented as a summary of [*TFE-5*].

6.8.1 Customer Segments

Spaceflight Customer Segments might be divided into three main groups, which, at the same time, are composed of some customer subgroups. The differentiation has been made according to the kind of service that the customers are interested in accessing:

- **Interested in designing satellite missions:** Mainly, the national Space agencies and government defence institutions. These sorts of customers reach great agreements with Spaceflight in order to correctly design the kind of mission that they need with all the parameters that the mission has to accomplish. These two customers are also interested in the data services, which would be the geospatial software development and cloud services, as well as obtaining data intelligence from the Earth Observation Imagery.
- **Launching and monitoring missions:** Private satellite companies from the aerospace sector are the main customers of this service, as well as consumers of the hardware-focused on satellite functioning that Spaceflight produces.
- **Data Intelligence Consumers:** This customer segment is composed of: those companies which make use of the satellite imagery and its intelligence for maritime surveillance purposes; those companies which are interested in acquiring frequently updated information; those companies which are settled in the location-based services; and lastly, those companies interested in acquiring imagery and intelligence focusing on resolution, which would be the infrastructure and engineering-related companies.

6.8.2 Value Proposition

The value proposition of Spaceflight is extensive; as it was said, the company is composed of four branches. Each of them has a slightly different value proposition, even when all propositions are related to satellite manufacturing, launching, operation, and data analysis. This value proposition encompasses areas such as:

- Satellite components and subsystems development (hardware development).
- Mission planning for external satellite companies.
- Satellite launching services, sold in 2018 to *Mitsui & Co. Ltd* and *Yamasa*, yet still operated by Spaceflight.
- Satellite monitoring through a network of ground stations all around the world.
- Services related to data analysis and intelligence, such as the geospatial software development and cloud services, or the *Earth Observation Data Intelligence*, which is sold to third parties.

6.8.3 Channels

In order to reach the company and obtain the products which have been acquired, the company offers the following communication lines:

- **Blogs:** In order to keep up with the company's evolution and product innovations.
- **Headquarters:** In order to directly communicate with *Spaceflight* and its personnel directly.
- **Web Page:** It offers the possibility to contract some of the company's services through it, and at the same time, it offers news and information about the company and its services.
- **Social Media:** In order to present and promote the company's products.
- **Online platforms:** *Spaceflight* trough *BlackSky* is developing two different platforms, Spectra and Events.

6.8.4 Customer Relationships

Customer relationships established between company and customer are indirect, which are the vast majority, and are established using online communications, or, in exceptional contract cases, direct. These direct relationships allow both parties to have more fluent communication when it comes to

developing products and services that need to be developed as collaborations. (i. e. The development of the *GEOINT Broker Platform* in collaboration with *NGA*).

6.8.5 Revenue Streams

The revenues which sustain the company's activities come from the commercialization of different products, being the most critical revenues those that come from the launching activities, which imply that Spaceflight launches and places on orbit the small satellites of the customers, and whose payment is fractionated, depending on the stage of the launching process. Other incomes come from mission planning fees, the recurrent payments from mission monitoring, the punctual payments from satellite specialized hardware sales, and finally, from the fees of the acquired Earth Imagery and intelligence related to Earth Observation services.

6.8.6 Key Resources

To develop all the activities essential for the excellent functioning of the company, Spaceflight owns a global network of ground stations to:

- Ensure the activities related to satellite monitoring, a fleet of launchers, and contracts with launching companies.
- Undertake all the launching activities, assets of satellite software, a fleet of satellites, a library of satellite obtained data
- Perform all the key activities with a remarkable number of human resources.

6.8.7 Key Activities

The company offers activities related to satellite launching and management, including satellite launching, mission planning, or satellite monitoring. These are a big part of the company's activities and revenues, as well as services related to Earth Observation Intelligence services, including geospatial software development, *Earth Observation Data Intelligence* creation, or geospatial cloud services. Lastly, its main activities would be related to satellite hardware production and delivery.

6.8.8 Key Partnerships

Some of Spaceflight's most important partnerships are these presented in the following lines:

- **Mitsui & Co. Ltd and Yamasa:** *Spaceflight* Industries reached an agreement with this Japanese company by the end of 2018 to sell its satellite rideshare subsidiary, Spaceflight Inc., to this company [8]. The deal would see *Spaceflight* continue to operate as an independent business based in the U.S and headquartered in Seattle, with the same mission of providing rideshare launch services for small satellite payloads [9].
- **NGA:** In September 2017, both companies announced the partnership agreement in order to develop and deliver a cloud-based geospatial intelligence broker platform for the *U.S Air Force Research Lab.* [10]
- **NASA:** In 2017, both entities signed an agreement of collaboration regarding the launch of U-class payloads. [11]
- **Thales:** In February 2019, *Thales* partnered with *Spaceflight* Industries to disrupt the smallsat industry, by producing cost-effective satellites at a new state-of-the-art smallsat production facility. [12]
- **Telespazio:** In September 2017, *Spaceflight* Industries and *Telespazio* signed a partnership agreement to realize the *BlackSky* constellation.[13]

6.8.9 Cost Structure

The development of productive and commercial activities reflects on a cost structure that the company needs to face. This cost structure is mainly composed of the data storage and processing costs, as well as the costs associated with the production of either intelligence, as well as the hardware production costs. Other essential costs that need to be taken into account are marketing and sales, human costs, and logistic costs, especially when planning the launching missions.

All the ideas previously described are summarized in *Figure 6.8*, and can be better understood after reading ***Appendix H***, which presents *Spaceflight Industries* case study, a detailed analysis of the company and its evolution.

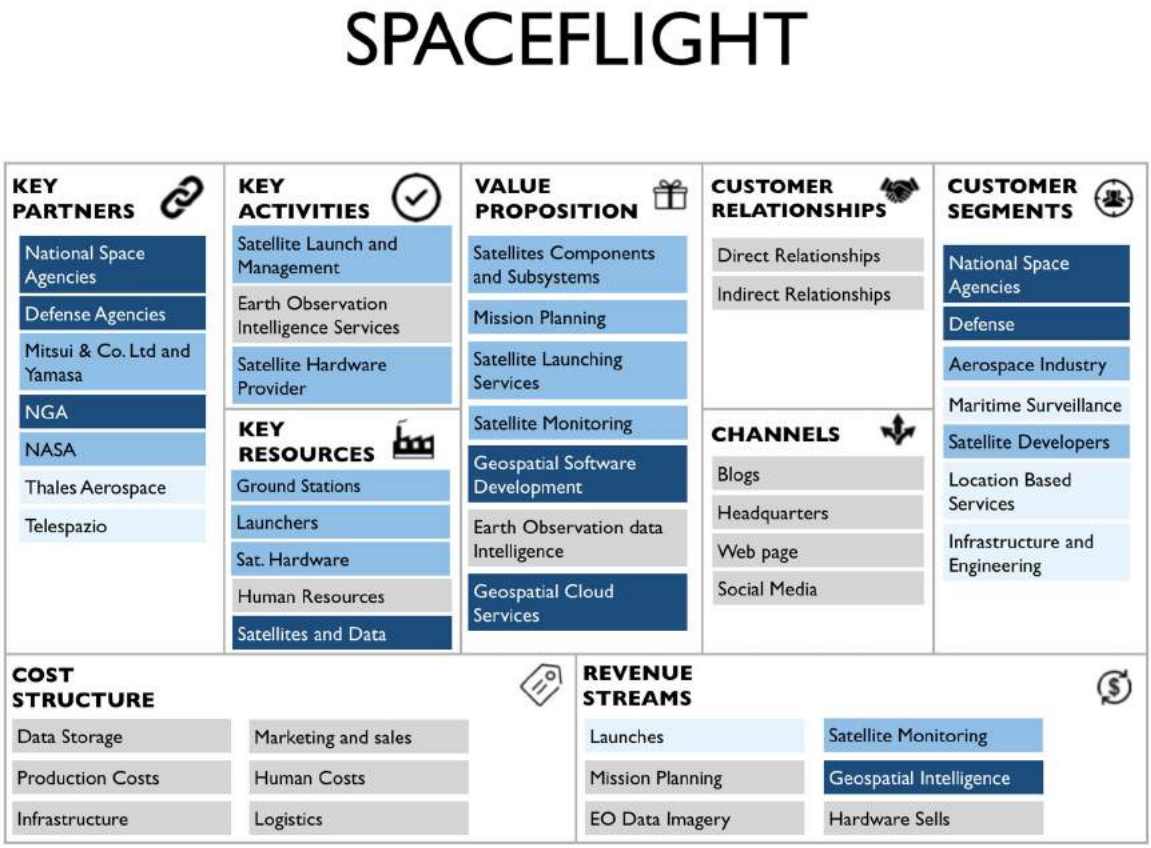

Figure 6.8 CANVAS Business Model for Spaceflight

7 Success Factors & Patterns analysis

After analysing the previous business models, it is interesting trying to see if a new business model pattern can be established in the world of Earth Observation or not. But what is a business model pattern?

7.1 Business model patterns

According to *Jay Liebowitz*, a business model pattern can be understood as a set of common behaviors that several business models exhibit [14].

The basic idea of the pattern concept is reusing solutions that are documented generally and abstractly to make them accessible and applicable to others. In this way, patterns seek to contribute to reducing complexity and increasing efficiency in problem-solving processes [15].

In the same way, the concept of business model pattern is ambiguous, and experts do not agree on a globally accepted definition. It is for that reason that it is crucial to dig into its classification. According to *Gausemeier and Amshoff* [16], there are three main categories:

1 **Frameworks:** located at the top of the pyramid, they are proven forms for the documentation and analysis of business models. This category is where the Canvas template and the Feedback loops are classified.
2 **Prototypical business models** permit a quick orientation when entering a new market but are not appropriate for developing new business models.
3 **Solution patterns:** located at the bottom of the pyramid and is the most extensive category; they are proven building blocks for designing business models.

These three categories are presented in Figure 7.1. Note that they are located in the pyramid according to their extensiveness, which means that there are many more solution patterns than frameworks.

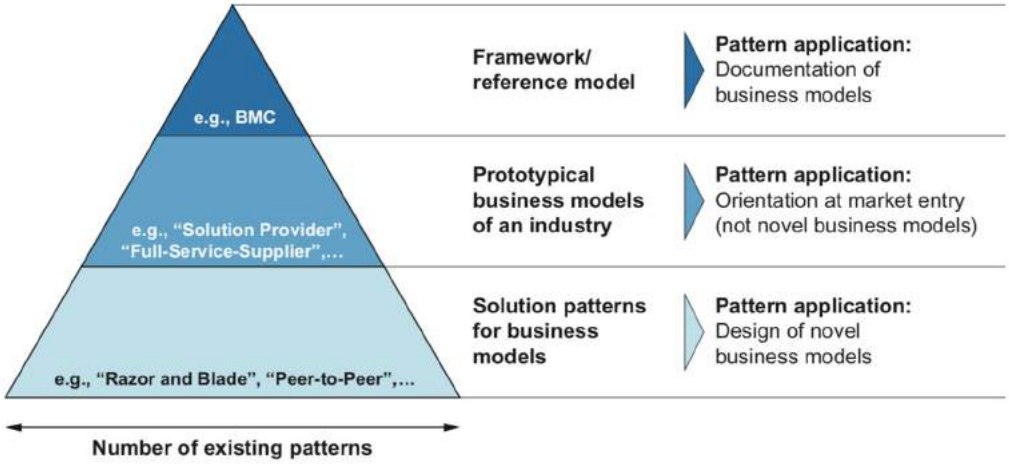

Figure 7.1 Classification of the business model patterns. Extracted from [16]

Once this classification has been introduced, it is worth noting that in this research, the attention will be focused on the third category, the solution patterns. Somehow the second category may seem more useful than the third one for the world of Earth Observation. However, this research aims to see which are the key factors to consider when designing a new business model. Thus, the solution patterns will enable the identification of the critical building blocks of the EO business models. Those help enterprises with the design or the innovation process of their business model.

7.2 Can DISCOVERER take advantage of a new business model pattern?

The title perfectly reflects the aim of this section: trying to conclude if a new business model pattern can be established in the world of Earth Observation, specifically the New Space trend. Therefore, one pattern of which the *DISCOVERER* project could take advantage of.

To do so, a systematic methodology has been applied. First of all, a set of requirements will be established to be able to gather all the information needed (*taken from section 6 of this document and its appendixes*).

The main idea is to identify if some characteristics are kept repeated along with the companies' business models. To do so, the pattern methodology will be applied.

As mentioned above, before starting with the methodology, some requirements have been established:

- All the enterprises analysed have to be focused on EO activities.
- The enterprises have to be vertically integrated.
- The enterprises cannot be all from the USA. To provide general results, enterprises from different countries are analysed.
- The enterprises should be unique to apply the case study methodology.

7.3 Pattern methodology

The pattern methodology consists of defining some configuration options for each business model variable and then, using a binary code to identify if a company opts for that configuration option.

The business models' variables are the set of factors that defines a business model element. In this sentence, some concepts need further explanation:

- **Business model elements.** In this research, the business model elements are the different building blocks of the Canvas template. Nevertheless, not all building blocks will be part of the pattern methodology, value proposition, revenue streams, and cost structure are out of the methodology:
    - Value proposition: due to their complexity, they have been analysed separately. In the State of the Art, the trends of the EO have been introduced. Then in section 6, all the value propositions from the different companies have been detailed.
    - Revenue streams and cost structure: these two building blocks are considered to be a consequence of the other one. Thus, if all the other blocks are analyzed, these two blocks will be automatically defined.
- **Business model variables.** They are considered to be the factors that best describe the business model elements. According to *Amshoff* [16], business model variables are levers a company uses for actively designing its business model.
- **Configuration options.** They are the different alternatives that can be found in each business model variable.

To better understand these concepts down below all the business model variables, their configuration options chosen for this research are detailed:

- Target group: It refers to the different groups of customers that a company aims to serve. Therefore, it can be said that this variable ultimately defines the customer segment building block. As different configuration options, general categories have been chosen. Customers in EO can come from the commercial, governmental, military, humanitarian, and educational sectors. It is worth noting that the commercial industry includes markets such as forestry, aviation, agriculture, energy, and insurance. However, for the methodology, it is not useful going deeply in that detail. Therefore, the pattern will be applied only, taking into account the general classification.

- Sales and delivery: sales and distribution are considered to be the key factors shaping the channels block. These two processes can be formed by direct or indirect and own or partner channels. However, as EO is a service entirely online, physical stores are disregarded. Taking all this into account, the configuration options considered for this variable are salesforce and web platforms.
- Type of service: according to section 5, the best factor that describes customer relationships is the type of service. As configuration options for this variable have been chosen, the different types detailed in *Figure 5.3*.
- Own activities: regarding the key activities building block for this research, it is essential to see which are their own activities. Due to this fact, like configuration options, all the activities from down, up, and middle streams have been considered.
- Owned physical resources: in the same way as key activities, it is important to see which are their own resources. Based on the activities from the EO value chain, the key resources are selected and placed as configuration options.
- Number of partnerships: the two aspects that define the key partnerships building block are the number of partnerships and their type. The configuration options for the variable number of partnerships are a high number or a low number of alliances.
- Type of partnerships: as mentioned above, another variable is the type of partnership. According to *Osterwalder [6]*, these partnerships can be strategic alliances, joint ventures, buyer-supplier relationships, and partnerships based on coopetition.

In *Table 7.1*, all these concepts can be found, and the methodology results are presented.

7.4 Pattern methodology results

As mentioned above, in this section, the results of the pattern methodology are detailed.

To better understand, it is vitally important to clarify that a binary code has been used: 1 means that the company shares that characteristic, whereas 0 means that the company does not present that factor.

Furthermore, taking into account the requirements detailed in *section 7.2*, the companies analysed employing the pattern methodology are:

- DigitalGlobe
- Planet
- Satellogic
- Spaceflight
- Spire
- Urthecast

Note that in section 6, other companies such as *Deimos* and *GOMspace* have been analysed. However, these companies are not considered to be totally vertical integrated, as they don't provide End-User services by themselves, they are disregarded from the pattern methodology.

From Table 7.1 it can be extracted that all companies serve more than one group of customers. All of them serve the commercial sector, and the vast majority also the civil one. Moreover, note that most of them provide their services to the humanitarian or educational sector too.

Table 7.1 Pattern methodology results

	BM variables	Configuration options	DigitalGlobe	Planets	Satellogic	Spaceflight	Spire	UrtheCast
			Company					
Customer segment	Target group	Comercial	1	1	1	1	1	1
		Governamental	1	1	1	1	1	1
		Military	1	0	0	1	1	1
		Humanitarian	1	1	1	0	0	1
		Educational	1	1	1	0	1	1
Customer relationships & channels	Sales and delivery	Sales force/ Partner	1	1	0	0	0	0
		Web platform	1	1	1	1	1	1
	Type of service	Personal asistance	0	1	0	0	0	1
		Self-service	0	0	0	0	0	0
		Automated services	1	1	1	1	1	1
		Communities	0	0	0	0	0	0
		Co-creation	0	0	1	0	0	0
Key activities	Own activities	Satellite design	1	1	1	1	1	1
		Satellite build and AIT	1	1	1	1	1	1
		Satellite launch	0	0	0	1	0	0
		Satellite operations	1	1	1	1	1	1
		Satellite data sales	1	1	1	1	1	1
		Satellite data analytic sales	1	1	1	1	1	1
Key resources	Owned Physical	Offices in more than two countries	1	1	1	1	1	1
		Satellites	1	1	1	1	1	1
		VAS sensors	1	1	1	1	1	1
		Launching vehicles	0	0	0	1	0	0
		Operated ground stations	1	1	1	1	1	1
		AI platforms	1	1	1	1	1	1
Key partnerships	Number	High number of partners	1	1	1	1	1	1
		Low number of partners	0	0	0	0	0	0
	Type	Strategic alliances	1	1	1	1	1	1
		Coopetition	1	1	0	1	0	1
		Joint ventures	1	1	0	1	0	0
		Buyer-Supplier relationship	1	1	1	1	1	1

Then, similarly to customer relationships and channels, all of them opt for online platforms. These online platforms enable them to reach all types of customers worldwide with reduced expenses. However, these platforms are automated-base services. To solve this matter, the companies are taking steps towards more tailored services through these platforms, both from investing in user interface and opting for personal counts.

When analysing the key activities and the key resources to develop them, it can be seen that most of them develop the complete value chain except for the launching activities. However, it is vitally important to note that they do not produce all the activities or handle all the resources on their own. Therefore, all of them opt for establishing a high number of strategic alliances.

However, one question that may arise is **why existing patterns cannot be adapted to this New Space trend**?

It is a well-known fact that nowadays, there are plenty of business model patterns that a business could take advantage of. Nevertheless, when trying to apply these methodologies to novel EO companies, some aspect is missing. A detailed analysis of the current patterns has been done to justify the previous sentence, starting from the most general category, the framework pattern, until the detailed ones prototypical and solutions patterns.

When talking about framework patterns, *Osterwalder and Pigneur* researchers did extensive work [6]. They identified five different patterns (*table 7.2*) : Unbundling, The Long Tail, Multi-sided Platforms, Free as Business Model, and Open business models. So, can the EO market be classified into one of these patterns? The answer is no.

Table 7.2 Business Model Patterns. Source: [6]

Pattern	Definition [6]	Reason
Unbundling	It is composed by three different types of businesses that they may co-exist within a single firm, but they are unbundle into separate entities in order to avoid conflicts or undesirable trade off.	Companies are not focused on one type of alternative competitive advantage
The Long Tail	It is focused on offering large number of niche products, each of which sells relatively infrequently. It requires low inventory cost and platforms to make niche content readily available to interested buyers.	They do not focus on selling a large number of products in low volumes.
Multi-sided Platforms	They are platforms that bring together two or more distinct but interdependent groups of customers. They create value as intermediaries by connecting and facilitating interactions between these groups.	Customer segments do not depend on one another and neither interact one to each other. All of them can exist without the others.
Free as Business Model	It is a business model where one substantial customer segment is able to continuously benefit from a free-of-charge offer. It is very popular in digitalization of goods and services offered via web.	Not all of the companies offer data for free, and the ones that provide the product for free is because they have an educational or humanitarian commitment.
Open business models	It is used by companies to create and capture value by systematically collaborating with outside partners.	This pattern, as the main idea is to allow to create value by collaborating with outside partners, could fit with the EO trend; however, it not encompasses other vitally essential facts of the market.

At the end of their study, *Osterwalder and Pigneur* authors claim, "*New patterns based on other business concepts will certainly emerge over time*" [6]. Therefore, it can be said that EO Space companies introduce new business concepts that will develop a new business model pattern.

However, *Gausemeier et al.* [16] identified 55 different mixed patterns (prototypical and solution patterns). Therefore, it is crucial to see if some of these patterns could fit the New Space idea. By reviewing their cluster, it can be concluded that the existing patterns cannot wholly define the EO market, and with that, this democratising trend requires a new pattern (Figure 7.2).

When trying to **democratise a service or a product**, it is vitally important to consider the needs and social concerns that new customers present. Usually, democratising means making **access to the commercial sector** through innovative and affordable services, a service that was previously wholly reserved for civil use. Therefore, companies have to focus their attention on **reducing the cost and complexity** by developing integrated IT platforms, small satellite technology, and lean manufacturing. To do so, EO opts for automated services like **Web-based platforms** that enable EO companies to **offer tailored and processed information at low prices** by reducing the variable costs, customizing the service, and analysing the imagery data. To cut expenses, companies have to focus their attention on the key resources building block. There, some standardization has to be introduced in order to be able to produce quicker and cheaper products.

Furthermore, to **strengthen the brand and key activities**, EO companies have to focus on the key partnership building block. There, some key activities have to be introduced in order to be able to build a strong market reputation, attract global commercial customers, and adapt quickly to market needs.

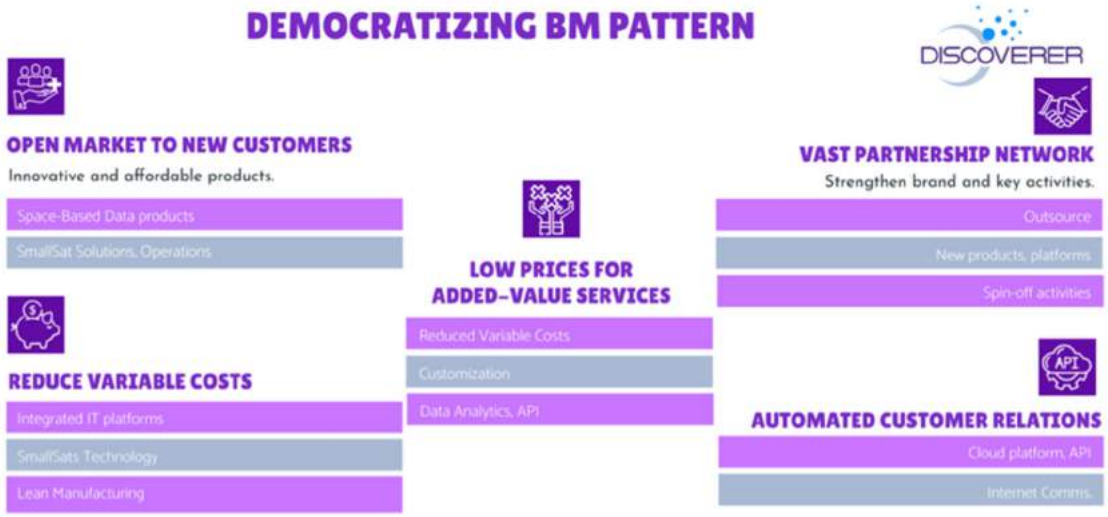

Figure 7.2 New business model patterns: Democratizing EO BM Pattern. Extracted from TFE-9.

Once the new pattern is defined, the key success factors of the market can still be identified (*table 7.3*). As mentioned above, these results were obtained through the pattern methodology.

Table 7.3 Key Success Factors in EO companies vertical integrated

Key success factors	Description
Smallsat Technology	Opting for small satellites should be a value proposition to be present in the fight for higher resolution, lower revisit time and manufacturing standardization.

Key success factors	Description
Partnerships	By establishing a high number of partnerships the company gains both reputation and reinforce its resources and activities.
Lean Manufacturing	It helps to reduce the manufacturing time and also provides complete control over the process and cost.
Satellite Constellations	Placing constellations of small satellites in LEO and VLEO enable the space community to obtain a huge amount of data in near real-time. It would transform EO imagery into a commercial product, taking benefit of their almost high resolution and their high revisit time.
Cloud-based analytics platform	When democratising activity, it is vitally important to invest in Value-Added Services (VAS). For the specific case of EO observation, companies invest in Cloud-based platforms to process the images.
Constant product innovation	Commercial customer segments involve a high degree of competence; therefore, applying recent innovations is crucial to be present in the market.
Vertically integrated strategy	This vertically integrated strategy enables companies to take control of the complete process of manufacturing from creation until delivery.

After identifying which are the factors all the studied companies share (*table 7.3*), it is interesting to see whether these factors can be considered key choices. To do so, the Feedback Loop methodology will be applied.

Note that the Feedback Loop Diagram (see *Figure 7.3*) represent circles where choices are linked to their consequences by arrows (explained in section 5). Hence, the legend used in *Figure 7.3* is: the choices are underlined; the rigid consequences are boxed and in a standard font are represented the flexible consequences.

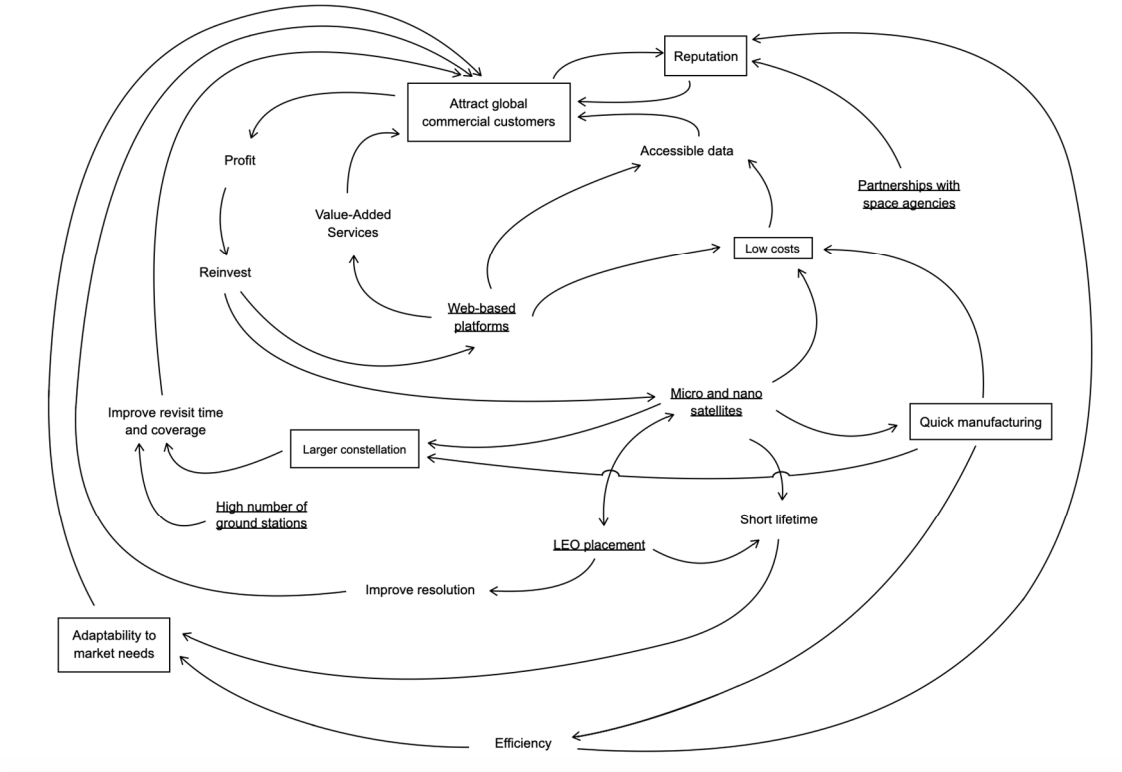

Figure 7.3 Feedback Loop Diagram

Figure 7.3 shows the feedback loops of a general vertically integrated EO company based on existing EO companies like *Spaceflight*, *DigitalGlobe* or *Planet*. One of the most important ones captures the vertical integration trend in the EO space industry. *Table 7.4* describes the feedback loops related to the observed key success. Additionally, *Figure 7.3* shows that critical choices are related to resources, channels, and customer relationships. However, if these results are consistent with the rest of the EO market, it is still wondered.

Table 7.4 Relationship between the Feedback Loops and Key success factors

Key success factors	Feedback Loops	Diagram loops
Smallsat Technology	Economic Feedback Loop	Small satellites >> Low-cost satellites >> Affordable data >> Attract commercial customers >> Profit >> Reinvest >> Small satellites
Partnerships	Partnership Feedback Loop	Partnership with space agencies >> talented employees >> quick manufacturing >> Efficiency >> Adaptability to market needs >> Attract commercial customers >> Reputation >> Partnership with space agencies
Lean Manufacturing	Production Feedback Loop	Small satellites >> Quick Manufacturing >> Large constellation >> Improve revisit time >> Attract commercial customers >> Profit >> Reinvest >> Small satellites
Satellite Constellations	Constellation Feedback Loop	Small satellites >> Large constellation >> Improve revisit time >> Attract commercial customers >> Profit >> Reinvest >> Small satellites
Cloud-based analytics platform	Cloud-Analytics Feedback Loop	Web-based platforms >> Value-Added Services >> Attract commercial customers >> Profit >> Reinvest >> Automated services >> Web-based platforms
Constant product innovation	Innovation Feedback Loop	Small satellites >> Adaptability to market needs >> Attract commercial customers >> Profit >> Reinvest >> Small satellites
Vertically integrated strategy	There is a loop that integrates the previous feedback loops that enable companies to take control over the complete process from design to image exploitation.	

Table 7.4 identify the different feedback loops created inside the big one (vertical integration). As mentioned in *section 5*, there can be virtuous (positive) or vicious (negative) feedback loops. Inside the loops presented in *Figure 7.3* five different virtuous loops can be identified:

1 **Economic cycle:** by adopting web-based channels, the companies reduce their costs, enabling them to offer more competitive prices that catch the attention of more customers. At the same time, these customers provide more profit that the enterprises can choose to invest in improving the online platform services.

2 **Production cycle:** The standardization level that the small satellites present is a critical factor that impacts quick manufacturing. Thanks to this time reduction and, at the same time, cost reduction, the company can build larger constellations and, with that, improve revisit time and coverage a value proposition that will catch new customers' attention. Then, these customers provide more profit that the enterprises can choose to invest in building more satellites.

3 **Innovation cycle:** it is a well-known fact that small satellites have a short lifetime. This factor is suitable when technology is evolving quickly. These short lifetimes enable the companies to adapt the service to the market needs quickly and attract more customers. These customers then provide more profit that the enterprises can choose to invest in adapting their new satellites.

4 **Value-Added Services cycle:** as mentioned above, the companies opt for online channels. With that, they can create Value-Added Services that will catch the attention of new customers. These customers then provide more profit that the enterprises can choose to invest in improving their online platforms.

5 **Partnerships cycle**: by establishing a high number of partnerships, the company gains a reputation that is traduced in acquiring new customers. Furthermore, these partnerships enable the company to obtain more key resources or key activities.

In the same way, it is vitally important to note that no vicious cycle can be found. However, this does not mean that over time one virtuous cycle somehow can revert and become vicious. To prevent that, isolated choices feeding these loops play an important role: items such as having a high number of partnerships and a high reputation reinforce the whole business model.

Summing up, the factors identified employing the pattern methodology are the ones that then, through the Feedback Loop Diagram, turn out to be crucial when creating rigid consequences. The higher the number of rigid consequences, the more competitive and robust the business model is. Due to this fact, when trying to enter the EO market, it is important to keep in mind these choices and then to try to reinforce the whole diagram by adding more competitive choices.

8 New Business Models

Once the key factors of the current successful players in EO have been identified, it is important to analyse if there exists the possibility that new enterprises take advantage of them at VLEO.

So, this section will include some **new Business Model CANVAS** developed from companies that would emerge from the most promising concepts extracted from *Deliverables D5.3 and D5.4*. Moreover, outline the fact that in order to be sustainable in the long-term, these companies will need to adapt the newly developed success factors (*section 7*) to their own strategies.

According to those previous deliverables, five groups of new Business Models can be generated, plus two already existing ones:

1. **Access to Space** : since there is a continuous increase the need for launching new satellites to serve the EO demand.
2. **Ground Station Services** : since the increase in the number of satellites al low orbits combined with the reduced communications window creates the risk to lose some of the achieved data if not transferred to Earth.
3. **Turnkey providers** : and, amongst them, those that can be identified as *Space Brokers*, to facilitate the preparation and launching activities.
4. **Very High Resolution – High Performance platform** (VHR-HP) : being one of the trends of EO at VLEO.
5. **Very High Resolution – Low Cost platforms (VHR-LC)** : already exploited by companies like *Planet* (*see section 6*).
6. **Constellations** : also *section 6*.
7. **Synthetic Aperture Radar** (SAR) : already exploited by companies like *Satellogic* (*section 6*).

8.1 Access to space

It is expected that the fact of having a large number of constellations, will increase the amount of satellites launched yearly, directly growing the need of sending all these platforms into space too.

Moreover, the objective of reducing costs increases the trend of launching smallsats (less than 500 kg) rather than the larger ones, provoking a bigger diversification in the access to space. This way, it was observed how in 2017 smallsats were preferred to be launched by medium size launchers, due to their compatibility issues and the launch opportunities their offered, achieving a decrease in the number of smallsats being launched as a piggyback on heavy launchers.

Hence, the sector is expected to evolve towards two very different extremes. On the one hand, the use of super heavy launchers will enable to place dozens or hundreds of satellites in orbit, allowing to develop mega-constellation projects. Besides that, on the other hand, micro-launchers solutions would be the perfect solution to place single smallsats into lower orbits.

The launch demand estimation can be seen in the *Figure 8.1*.

So, in this section the business model of a **micro-launcher company and a rockoon company** will be studied.

A **micro-launcher** is a small rocket used to launch small satellites to a specific orbit. The information used for developing this section's study was extracted from theses [*TFE-10*], [*TFE-11*] and [*TFE-12*].

A **rockoon** is a launching system which combines the rocket technology with a high-altitude balloon. Here the idea is to launch the rocket, which has the satellite inside, to the stratosphere by taking advantage of the fact that the air drag is lower in the stratosphere, allowing to use a smarter rocket or to arrive into higher altitudes using the same amount of propellant.

Hence, it can be concluded that the fact of using this new concept will allow to reduce the propellant-linked emissions and also it will enable to recover the balloons after each launch, avoiding waste in

materials and effort. The information used for developing this section's study was extracted from [*TFE-14*].

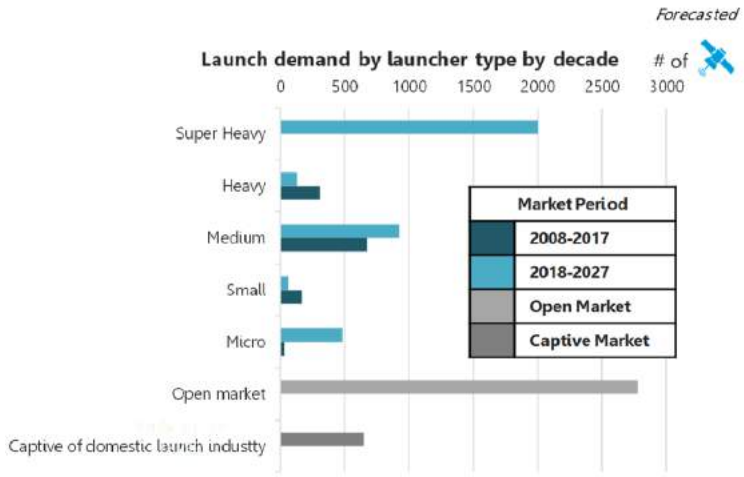

Figure 8.1 Comparison of launch demand by launcher type by decade (Euroconsult)

So, it is seen how in both business models the research component is important as the technology is new or under development. Hence, designing a micro-launcher will be one of the main challenges of the new access to space age. Besides that, highlight that integrate this new technology with a balloon will become more complex and challenging.

8.1.1 Customer Segments

The customer segments of a company can be described as the niche market which aims to have a specific service.

Consequently, different customer segments have been identified along private and public sectors, always with the objective of launching small satellites at VLEO or LEO:

- **Commercial Earth observation companies** aiming to place a small satellite into a specific orbit such as: *Planet, Satellogic, Deimos, GOMSpace*, etc
- **Commercial communication companies** with economic power that want to place a small satellite in VLEO or LEO.
- **Government and defence** institutions without an own launching system, which aim to launch a satellite for: Defence, intelligence, surveillance, meteorology, among others.
- **Space agencies** that don't own a launching system and that aim to launch small satellites, such as: *NASA, ESA, JAXA*, etc.
- **Academic institutions** willing to launch small satellites and research projects that have a reduced budget, such as: Research centres, universities, schools, etc.

In the *table 8.1*, the summary of this initial building block can be found.

Table 8.1 Access to space customer segment

Micro-launcher company	Rockoon company
Similarities	
• Commercial EO companies • Commercial communication companies • Government and defence • Space agencies • Academic institutions	
Differences	
-	-

8.1.2 Value Proposition

The conventional launchers, offer the satellites companies to send their platforms to space as one of the many devices they send or as a secondary payload, called piggy-back. Hence, with the current situation, it is impossible to choose some parameters like: the specific orbital details, schedule, among others.

For this reason, **micro-launchers** are defined as a satellite launching solution which offer the possibility to develop launches perfectly suited to the client's needs, providing a great degree of control on the mission parameters, achieving an even more accurate service in the launching and deployment processes and expending less time in the launching phase than with regular rockets.

On the other hand, as it was previously said, launching with a **rockoon** will reduce the amount of fuel needed and consequently reducing the emissions it produces, becoming an almost eco-friendly device. Moreover, since the first phase of the launching will be done using a balloon, the vibrations of the vehicle will be reduced, making the flight safer for the satellite and allowing the company to recover and reuse the balloons.

In the *table 8.2*, this second building block is summarized.

Table 8.2 Access to space value proposition

Micro-launcher company	Rockoon company
Similarities	
● Customized launching service ● On-demand schedule ● Customized mission parameters ● Affordable price	
Differences	
● Great degree of control of the mission parameters ● Accuracy in launching and deployment processes ● Reduced launching time	● Reusable vehicles (balloon) ● Less vibration ● Eco-friendly (less emissions)

8.1.3 Channels

Analysing the way in which the companies would communicate with their potential clients, it is considered that a fluent communication would be the optimal choice. So, in order to achieve it and regarding the phases of the client's decision, the communication channels have been divided into: **Catching, capturing and converting customers**.

So, the first step would be to catch the customers' attention by advertising the launch service. This way, it is thought that the system could work with a web-based platform, where the companies would be able to make a preliminary communication with their potential clients, letting them to book the launching spots, study their options, etc.

Moreover, in order to introduce this technology and provide the necessary information into the potential clients, the companies would also have to create a communication and sales force team, and to develop an engineering team which will allow to discuss the specific mission's details.

In the *table 8.3*, the summary of the building block can be found.

Table 8.3 Access to space channels

Micro-launcher company	Rockoon company
Similarities	
● Catch customers: social media, conferences, web page, journals, advertisement ● Capture customers: web-based platform, dedicated communication and salesforce ● Convert customers: dedicated salesforce and engineering team	
Differences	
-	-

8.1.4 Customer Relationships

The kind of relationships that the clients expect to maintain with this kind of companies, involves having a launching insurance which fulfils the current legislation and that will protect their investment, whose technology is constantly being updated.

On the other hand, companies can offer to regular customers a reduction in costs or time preferences, using loyalty methods and personal assistance if needed.

In the *table 8.4*, the building block is summarized.

Table 8.4 Access to space customer relationships

Micro-launcher company	Rockoon company
Similarities	
● Launching insurance ● Updated status of the mission ● Loyalty methods ● Personal assistance	
Differences	
-	-

8.1.5 Revenue Streams

The most representative revenue stream in economic terms, is the launching fee. Therefore, it is considered that the launching fees will involve individual payments per launch and the launching insurance, which price might differ between customers due to the loyalty discounts or the addition of extra features. Hence, it is possible that some of the loyalty status may involve a payment due to the client's will of getting other advantages.

Moreover, in case that a micro-launcher company decided to build its own launching infrastructure, another income might come from renting the installations to secondary users, becoming then a launchpad provider.

In the *table 8.5*, the summary of the building block can be found.

Table 8.5 Access to space revenue streams

Micro-launcher company	Rockoon company
Similarities	
● Launching fee ● Extra features addition ● Loyalty payments	
Differences	
● Launchpad renting	-

8.1.6 Key Resources

The key resources can be split into physical, intellectual and human. Besides, spotlight the fact that the resources required to develop both businesses are really similar, since both business models need to develop a rocket although the rockoon company needs to also develop a balloon and it's integration system.

This way, the similarities are:

- **Physical resources:** Both need to use psychical resources such as the facilities and the equipment needed to develop the project (research centre, ground station, communication room, etc.), the rockets and the web-platform used to contact with the clients.
- **Intellectual resources** such as the patents.
- **Human resources:** Having a high qualified staff is a requirement.

Nevertheless:

- The **micro-launcher** company needs to consider a launchpad which allows the rockets to be launched.
- The **rockoon** company needs to add the balloons, their launching platform and their recovery system. Moreover, as this company needs to mix two different technologies, a differentiated researcher team dedicated to each area is needed. Finally, it is important to remark that the rockoon system would need less fuel than the micro-launcher.

The *table 8.6* summarizes the building block.

Table 8.6 Access to space key resources

Micro-launcher company	Rockoon company
Similarities	
• Facilities and equipment • Rockets • Web-platform • Patents • High qualified staff (rockets)	
Differences	
• Launchpad	• Balloons • Launching platform • Recovery system • Balloon researcher staff • Less fuel

8.1.7 Key Activities

Initially, the key activities will be related to produce and manufacture the vehicles, starting with the research and development of the required technology in order to ensure the feasibility of the business. Afterwards, once that the vehicles are assembled, the key activities will be basically focused on managing and scheduling the satellites' launches in order to have revenues, taking into account possible marketing activities, as the commercial side of the companies cannot be left behind.

Moreover, outline that another key activity that a **micro-launcher** company may need to do, is to rent a launchpad in case it does not have the necessary facilities to do it.

On the other hand, the **rockoon** company mainly needs to focus itself on the research of the new technology that they are trying to develop, considering the extra steps that a two-phase launching mission may have. This means adding to the activities list items such as the research and development of the integration system of the balloon and rocket, the second stage launching, the geolocation and recovery of the balloon and the research of guarantee the stability of the mission.

In the t*able 8.7*, the building block is summarized.

Table 8.7 Access to space key activities

Micro-launcher company	Rockoon company
Similarities	
• Research and development • Manufacturing and production • Launching services • Marketing activities	
Differences	
• Launchpad renting	• Balloon and rocket integration research • Stability and accuracy research • Second stage launching • Geolocation and recovery of the balloon

8.1.8 Key Partnerships

Key Partnerships are an indispensable factor to ensure the companies' success. This way, some possible options for the micro-launcher and the rockoon companies are presented:

- **Space agencies**: They can provide to the company, through cooperation agreements, the necessary rights and permissions for certifying the launching vehicles. Moreover, this kind of partnership may allow to receive extra funds and resources to develop the required technology.
- **Research centres and universities**: They can provide high level knowledge according to their talented and skilled staff and also can collaborate through some research projects related to the companies' needs. Moreover, it is necessary to also treat them as possible customers.
- **Suppliers:** They are a main partnership, as they will provide the required elements to develop the service, directly affecting to the final costs of the project.
- **Small satellite developers:** They would provide inputs for the vehicle requirements, being potential customers.

Moreover, it is important to outline that the micro-launcher company may need to consider the launchpad providers in case it doesn't have its own platform.

In the *table 8.8*, the summary of the building block can be found.

Table 8.8 Access to space key partnerships

Micro-launcher company	Rockoon company
Similarities	
• Space agencies and governments • Research centres and universities • Suppliers • Small satellites developers	
Differences	
• Launchpad providers	-

8.1.9 Cost Structure

The final cost will be defined by all the activities, resources and partnerships previously explained, being divided in different sections. This way, some of the sections where the cost would be more relevant, are:

1 Launching costs:

- Facilities and equipment for the launch.
- Licences, taxes and insurance for doing the launch.
- Fuel and supplies.

2 Development costs:

- Facilities and equipment for doing the R+D and the required tests.
- Team salaries.
- Quality control.
- Licences, taxes and insurance for doing the tests.

3 Operational costs:

- Define the patents for the developed technology.
- Marketing costs of the company.
- Web-platform maintenance.

This way, in the *table 8.9*, the building block is summarized.

Table 8.9 Access to space cost structure

Micro-launcher company	Rockoon company
Similarities	
● Facilities and equipment ● Fuel and supplies ● Web-platform maintenance ● Patents ● Salaries ● Quality control ● Licences, taxes and insurance ● Launching cost ● Marketing cost	
Differences	
● Rocket manufacturing ● Launchpad renting	● Rockoon manufacturing ● Balloons maintenance ● Recovery ● Higher R&D investment

In order to summarise the previous points, a **CANVAS business model** for the **micro-launcher** company and the **rockoon** company has been developed in *figures 8.2* and *figure 8.3*.

MICRO-LAUNCHER COMPANY

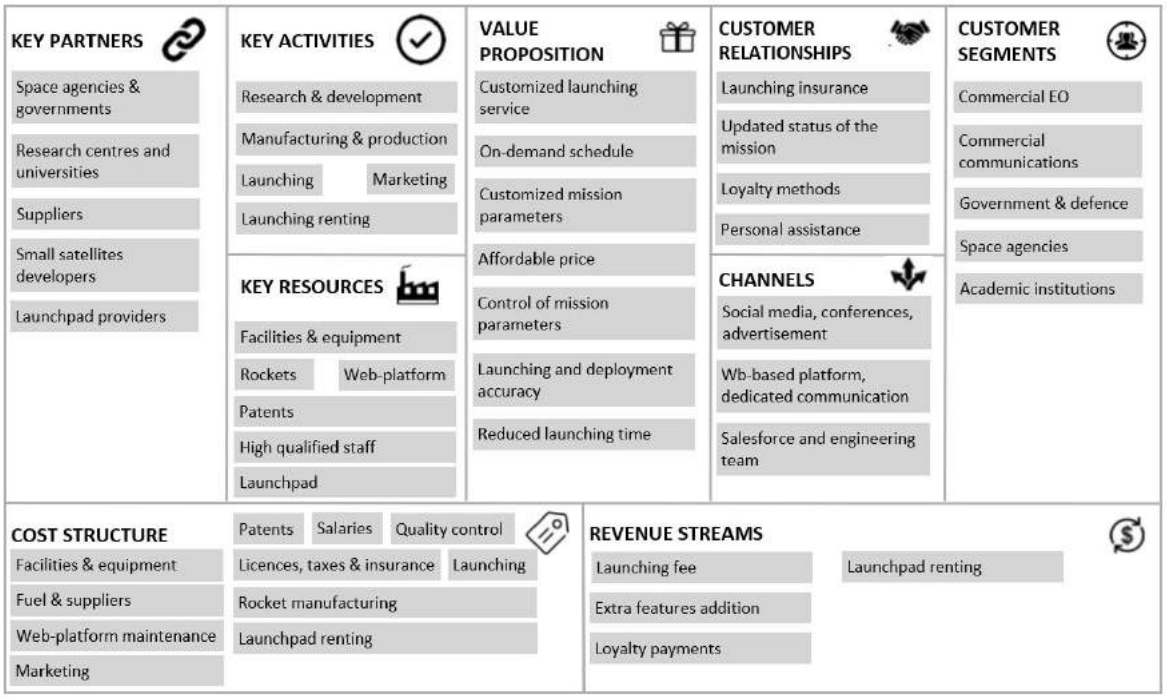

Figure 8.2 Business model canvas of a micro-launcher company

ROCKOON COMPANY

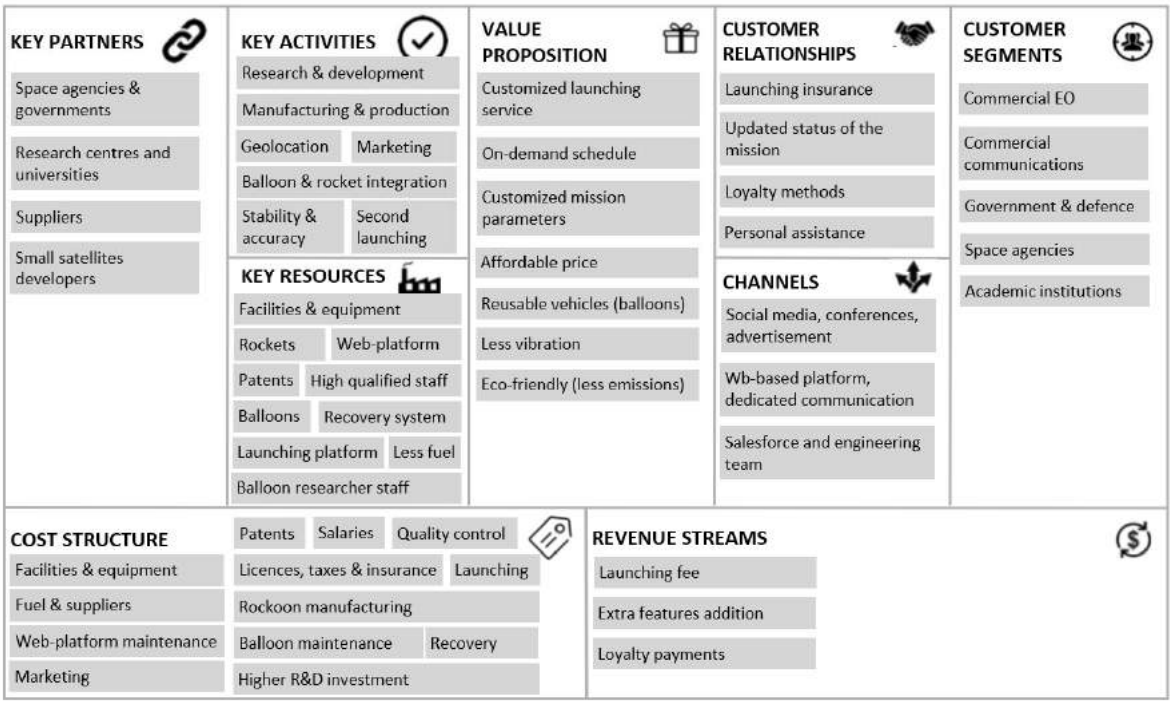

Figure 8.3 Business model canvas of a rockoon company

8.2 Ground Station Services

Ground stations are used to bi-directionally communicate the Earth's bases with the satellite, allowing to transmit commands, receive scientific data and obtain information as the satellite's status or its telemetry. Moreover, as the communication is made every time that the ground station is inside the satellite's signal range, this provokes the need of having a tailored information-storage module in the satellite which accumulates the data between each revisit time.

So, the Ground Station industry supporting EO programmes have experienced an evolution in terms of demand in the last decade. Besides, everything suggests that in the following years the industry will grow some 40% more [17], increasing the number of ground stations due to the high demand on EO data and value-added services.

Hence, in order to handle the challenge of the growth of the EO satellite market, the ground station industry will consider new goals, such as:

- The creation, in new locations, of affordable ground stations specialised in VLEO operations.
- The use of multi-mission ground stations.
- The complementarity of existing resources and the hybridization between physical and digital ones.
- The implementation of the *Electronically Scanned Array* technology, which will be able to track simultaneously several satellites, achieving higher data rates transmission due to the use of the *Ka and Ku bands* [18].

This way, the business model of a Ground Station Services company is studied, extracting the information from [*TFE-15*].

8.2.1 Customer Segments

As the EO-VLEO market is a niche market not yet fully developed, the ground station company may focus in EO satellite operators as possible customers. Hence, expertise should be focused on providing services to those operators included in one of the following EO sectors:

- **Environmental monitoring:** Real-time monitoring of the environment for preparing impact assessments. Outline the fact that the impacts can be caused by natural or human activities.
- **Infrastructure:** Companies specialised in the revision and control of critical facilities.
- **Location Based Services (LBS):** Companies specialised in georeferencing.
- **Natural resources monitoring:** Companies specialised in the preservation of the natural habitat and the analysis of the situation of the most endangered zones.

8.2.2 Value proposition

As the VLEO satellites will have different characteristics than the traditional LEO satellites, it is important to add brand new points to the value proposition list, obtaining:

- **Exclusive infrastructure:** Facilities specialised in managing VLEO missions.
- **Multi-mission bases:** Using Electronically Steered Array antennas for accomplishing the future VLEO demand, providing scalability to the business and being able to manage more than one mission at the same time.
- **New access regions:** Using smart places which will allow to reduce the latency in VLEO operations.
- **Reduce the contact time:** Using higher downlink Ka/Ku-bands frequencies.

- **Enhanced value chain:** Developing an automated, affordable and quality services which are complemented by the use of efficient VAS data.
- **No lost costs:** Implementation of a subscription fee based system.

8.2.3 Value proposition

Regarding the way in which the companies would communicate with the potential clients, the most appropriate way to do so would be to use a combination of direct and indirect channels:

- **Online platform/interface:** The implementation of this direct channel will allow to make all the required operations between the ground station company and the satellite operator, as the capacity of contracting the service or to deliver the necessary information.

- **Capacity aggregators platforms:** The implementation of this indirect channel will also allow the contract of services from the satellite operators and clients. Moreover, it is also possible to deliver the contracted services, mainly data.

- **Website:** The implementation of this direct channel, the potential clients and the general public will be reached. Moreover, it will also provide the gateway to the online platform for the clients.

- **Ground station company commercial/sales team:** The creation of a sales team will allow to capture clients by contacting them either digitally or in person. Besides, it is important to outline the fact that a commercial team will also be created, as it will be in charge of the company's promotion.

Hence, through the stated channels, the evaluation, purchase, delivery of services and after sales phases will be carried out.

8.2.4 Customer Relationships

Customer relationships will be focused on customer fidelity building and they will be managed differently according to the type of client or partner:

- Clients with higher potential revenue production will require personal assistance. Nevertheless, operations will still be completely automated through the ground station company platform, but additional, dedicated, personal assistance will be provided.

- Regular and private satellite operators, academic and non-profits clients will be assisted through automated services, via the company's ground station platform.

Besides, as part of the customer acquisition strategy, in any case there will be the possibility of co-creating the product with the customer until it is determined. Then, the corresponding relationship management presented before will start to be applied.

8.2.5 Revenue Streams

It is considered that the subscription fees will be the main revenue stream of the company. As a result, a monthly subscription will be made for each customer, providing three different levels of subscription, according to the customer needs:

- Base fee:

  This is the level recommended for occasional users, as they will only pay for what they use, not paying in case they have not used the service during the month. It is a service offered through the capacity aggregators, which works as a usage fee for every time that the customers use a

ground station to communicate with the satellites. In this case, no VAS services are included, although the customer's data will be preserved and studied by the ground station company.

- Advanced fee:

  This is the option recommended for the customers that directly book the services with the ground station company. The plan includes the customary VAS developed by the ground station company and a generous number of contacts are included per month, getting different prices for the different total number of contacts included. Outline that the contacts list will be suited depending if the customer is interested in the single satellite operators or the constellation ones.

- Pro free:

  This is the option recommended for the customers which produce a higher revenue for the ground station company due to their ad hoc petitions. Hence, this service will include specific dedicated VAS, aside from the customary ones. Moreover, a price for the service is previously fixed according to the satellite operator's requirements.

8.2.6 Key Resources

The key resources can be split in four groups, getting:

- **Physical:**
  - Central offices and the required facilities to develop the work.
  - Cloud installations, from a key partner.
- **Financial:**
  - It includes the lines of credit to assure continuous operations, especially at the beginning of the enterprise.
- **Technological:**
  - The equipment to make operations with satellite operators possible.
  - The software platform and the interface required for producing the Value Added Services
  - New technologies capabilities as: Artificial Intelligence, Blockchain, Big Data analytics, API, among other.
- **Human:**
  - High skilled technical staff specialised in the required brand new relevant technologies.
  - High skilled commercial profiles in order to promote the ground station company products and services.
  - High skilled UX/UI designers and business analysts to deliver the best experience to the clients and maintain the offer and the value proposition of the ground station company faithful to the reality of the market.
  - High skilled administration profiles, including financial and project managers to ensure the smoothness of the ground station company activities.

8.2.7 Key Activities

As the ground station company will have a platform as main key resource, it seems clear that the company's key activities will be related to continuous development and maintenance of the platform, being the most remarkable:

- **Daily operation of the ground station network:** Related to the normal procedure of the company's projects.
- **Big data management:** Based on the IT activities related to the data processing.

- **IT maintenance operations:** Developed to maintain the company's internet interface (or website) and the data treatment software, which generates most of the VAS activities.
- **Facilities maintenance:** Focused on maintaining the ground station network, mainly their antennas.
- **R+D:** Continuous improvement of the IT services and the data treatment software.
- **Marketing**: Focused on the customer relations and the promotion of the ground station company products and services throughout the VLEO-EO market, finding potential clients and ground capacity aggregator companies.

8.2.8 Key Partnerships

Key Partnerships is an indispensable factor to ensure the companies' success. This way, some possible options are presented:

- **Cloud provider:** A strategic alliance relationship will be stablished in order to develop expertise in the sector, on the other hand the cloud provider could use the platform as a test bench for the implementation of new advancements.
- **Academic (Universities) and/or research institutions:** A strategic alliance relationship will be stablished with this kind of institution in order to keep the employees updated on the technologies used as key resources. In exchange, the institution will be able to access to the ground station company platform and use it as a research asset for the development of new applications of these technologies, as well as to offer to its students learning opportunities linked with the ground station company. Outline the fact that some universities have their own ground station or antenna. Hence, this is also an opportunity to extend the network of the ground station company, as well as to place new antennas in University domains.
- **Capacity aggregators:** A *coopetition* relationship will be stablished as these companies are targeted partners. Hence, the ground station company will be able to manage some of the capacity aggregators' antennas unused time, offering it as own for the ground station company's network.
- **New players**, including a group of innovative dedicated ground station network providers: A partnership will also be done with one of the new players with mission control capabilities in order to be able to offer a more complete value chain.
- **European Space Agency:** As EO represents an important part of the agency's budget, a partnership will be pursued to collaborate on its programmes and gain knowledge through it.
- **Governments:** Strategic partnerships will be sought with Governments of several countries, mainly excluding any Defence related activities. Special focus will be made in reaching agreements with the Governments located in the new access regions.
- **EO big satellite operators:** A strategic partnership will be done in order to develop the VAS they need. Hence, an enhanced optimisation and lower data retrieval latency is obtained for the satellite operators and the final clients.

8.2.9 Cost Structure

The cost structure of the ground station company will be value-driven, as it will focus on maximising the value offered to the customer. This way, some of the sections where the cost would be more relevant, are:

- **Physical:**
  - Equipment and infrastructures ownership.
  - Equipment and infrastructures maintenance.
- **Financial:**
  - Assurance.
  - Interests from the subscribed lines of credit.
- **Human:**
  - Staff resources.
- **Technological:**
  - Administrative software and services.
  - Operations: platform software management.
  - VAS services capabilities management.
  - Cloud services.
- **R+D and other activities:**
  - Researching.
  - Marketing.

In order to summarise the previous points, the CANVAS business model for the Ground Station Services have been developed in *figure 8.4* Obtaining:

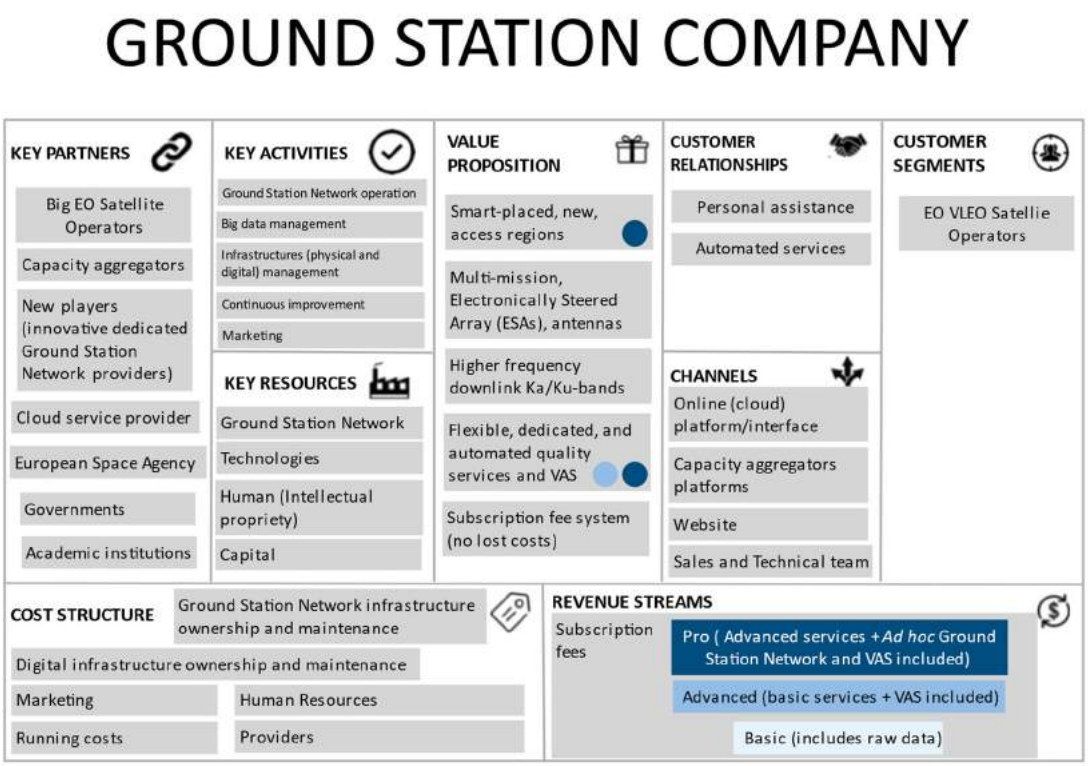

Figure 8.4: Business model canvas of Ground Station Services

8.3 Space Broker Company

The increasing number of satellite missions has given birth to turnkey providers for the preparation and launch part of the value chain of a mission. These are the so called Space Brokers and this chapter will analyse the corresponding CANVAS business model for a Space Broker Company focused on VLEO Missions, extracting the information from [*TFE-16*].

8.3.1 Customer Segments

It is important to outline the fact that the market segments that might be interested in the services that this kind of company could offer do not represent a large spectrum, as the service is focused on a specific and concrete service: launching small satellites into VLEO. Hence, the specific customer segments which may be interested in it, will be defined as ***Niche Market***.

This way, three subcategories of customers might be defined:

- **Research institutions**: Universities and other research institutions which can be interested in the study of the environment variation in VLEO and would potentially launch small satellites to undertake this kind of research.
- **Personal use:** Due to the costs reduction that the *New Space* might reach, individuals could end up being interested in sending their own small satellites into space.
- **Earth Observation**: Mainly targeting those companies which will operate their small satellites inside the VLEO.

8.3.2 Value Proposition

The main points that reinforce the project and that can match with what the potential clients want, are listed in the lines below:

- **Newness:** Achieve and offer a unique service which is focused on a part of the market that does not exist yet.
- **Customization possibility:** Regard the possibility of choosing the launch date and orbit parameter that best suits, offering small prices.
- **Easiness:** In the way that the service could help small companies to achieve their complex needs and speed up the process.
- **Quality and Performance:** By ensuring safe launches and the integrity of the launched satellites in all the phases of the spacecraft's deployment.
- **Environment Issues:** By reducing the amount of space debris which are generated.

8.3.3 Channels

The way which the company communicates with its potential customers, is divided in three parts:

- **Advertising stage**: Some advertising strategies would imply advertisements in different media, with the objective that the company could start settling its name and offer.
- **Direct contact.** It is a crucial stage which tries to convince the customers of making use of the services that the company offers. This way, the contact could be established through direct means. An example could be to provide the potential customers with a demo *SpaceApp* where the potential client could check all the possibilities that are offered.
- **Face to face assistance:** In the final part of the communications, meetings would have to take place in order to define the vicissitudes related to the launching parameters.

8.3.4 Customer Relationships

The communication process consists on directly work and collaborate with the costumer in order to help him with to design its launching strategy. It is important to outline the fact that communication between customers and business is a crucial point of a project's development, which has to be done once that a customer has decided to acquire the offered services. For this reason, devoting personal assistance to each of the customers should be taken into account.

This way, in order to help the client with this process, the development of an app is suggested. Besides, highlight that the app should be designed to provide the customer updated information related to the launching status.

8.3.5 Revenue Streams

At the time that the revenue streams are designed, one issue of a Space Broker company is to be considered, that is the price that the customers are going to pay for the acquired service. It usually will be paid in different fractions according to the features of the satellite which will be launched. This way, the company will charge the clients for a usage fee and therefore, if the client needs to use the service again, a new payment will have to be made.

Hence, it is noticed that the only circumstance that could interfere in this payment would be the fact that the process of launching the satellite ended up in failure.

8.3.6 Key Resources

In order to develop its value proposition, the company will require from a series of Key Resources:

- **Physical resources**: Mainly the communication equipment.
- **Non-tangible resources:** Which includes the communication platform, the assurances and the possible guarantees.
- **Intellectual resources:** Focused on the development of the technology improvements.
- **Human resources:** Being formed by a group of highly qualified employees which can be distributed in different countries, as they would need to communicate with business partners and customers.
- **Financial resources:** Mostly focusing in achieving the necessary funds for accomplish the required budget for developing the project.

8.3.7 Key Activities

Moreover, the main activities that the Broker company would have to perform in order to successfully operate are those focused on the platform networking, the service development and the problem solving considered and explained below:

- **Service production:** It considers the research and investigation in order to offer to the customer updated and high quality services, making agreements with new partners.
- **Problem Solving:** It involves the communication with customers and partners in order to satisfy the client's needs.
- **Platform/Network:** It is formed by different points, such as: Development of the software for constantly having the website updated, company branding, advertisement and the development of a customer's-to-company communication app.

8.3.8 Key Partnerships

Basically, the main partners that a Space Brokers company is interested in having would be the Space Agencies and other private companies that schedule the launches for larger satellites, as they can be potential launching providers. Additionally, other partners that can be interesting to have, would be the other new companies which own micro-launchers.

This way, for this kind of company is critical to have key partnerships, as the number of launchings that they could serve would be related to the quantity of customers which contract its services. Therefore, this sort of relationship would represent a quid-pro-quo situation for both partners.

8.3.9 Cost structure

The final cost will be defined by all the activities, resources and partnerships previously explained, being divided in different sections. This way, some of the sections where the cost would be more relevant, are:

- **Employees:** Mainly considering the salaries of the people who are working in the company.
- **Equipment:** As can be the costs of the facilities and the costs of achieving the required technology, as for example: renting of offices, achieve the required software for the computers, amongst others.
- **Platform:** This point basically is formed by the cost of maintaining the infrastructures and facilities that the company would own.
- **Marketing:** Regarding to promote the company and advertise it.
- **Technology:** Regarding the development of the app and other required software technology.
- **Software maintenance:** Formed by the costs of maintaining the IT services of the company.
- **Assurances and guarantees:** It is necessary to have the company ensured in case of launch failure.

This way, all the parameters previously explained, have been summed up in *figure 8.5*, which represents the CANVAS business model for a Space Broker company that based its operations in VLEO launches.

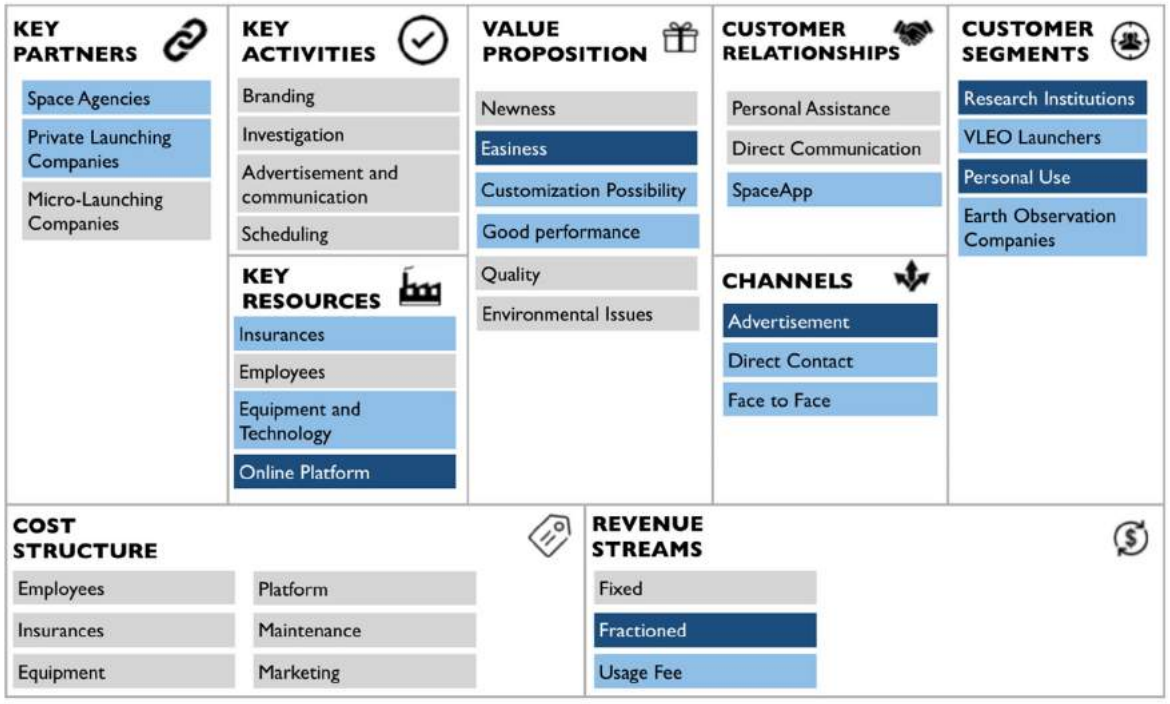

Figure 8.5 Business Model for a Space Broker company

8.4 Very High Resolution – High Performance platform (*Deimos sat4EO*)

As it was shown in section 6, *Elecnor Deimos* is a Spanish company specialised in the sector of Earth Observation which is planning to design a brand new optical sensor that will have a higher resolution than the current ones. Being implemented in a new platform that will be placed at an altitude of 500 km.

Therefore, the initial *Deimos Space's* idea was to launch a mini-satellite at VLEO, achieving a processed resolution of around 30 cm. Nevertheless, after some ups and downs during the process, it seems that the final design would consider a high specification satellite placed in a 225 kg platform at 500 km.

This way, after the success of *Deimos-1 and Deimos-2*, it is considered that the *Deimos* new satellite, (called *sat4EO*), would be smaller, cheaper and more agile than the ones from the competence. So, in order to make this possible, the company is using ESA and EU funds to develop a new Operational Control System (OCS) that will provide all the agility and accuracy that a very high resolution satellite will need.

The presented information and the company analysis are extracted from [*TFE-6*] and [*TFE-13*].

8.4.1 Customer segments

It is important to spotlight the fact that the customer segments that this platform will present, will be really reduced, because of the strict specifications and requirements than the satellite needs to accomplish. Moreover, the possible potential clients should have high standard needs and a large initial capital also reduces the segment's size. This way, the segments identified are:

- **Location Based Services:** Mainly focused on sub-metric targets, such as: Urban development, traffic monitoring, self-driving technologies, among others.
- **Engineering and infrastructure:** Includes the services to monitor rural development projects and big engineering projects, such as power plants.
- **Defence and security:** It considers the projects related to the army and the state protection, including projects inside the field of IMINT (Imaginary Intelligence), surveillance, border monitoring, among others.
- **Disaster management:** Focused on helping and managing disasters after they have happened, by capturing high resolution images of the ravages in order to analyse the Earth's surface and the affected territory, with the idea of having a faster, safer and accurate answer.

8.4.2 Value Proposition

As *Sat4EO* will be a brand new satellite, its main points will be the higher, newer and more accurate specifications that it will present. Outlining the new integrated software (*Deimos 4EO software*) which would allow the client to interact with the platform.

Moreover, taking advantage of the higher resolution that the satellite will present and considering that it is thought to be used inside the Earth Observation sector, the images provided by the satellite are planned to be distributed inside the market at a competitive price, giving also an image value-added service, as the possibility of improving the obtained images with newer post-process, the use of artificial intelligence algorithms, etc.

This way, some of the most relevant specifications that the *sat4EO* presents, are:

- **The very high resolution:** Achieving a 50 cm x 30 cm resolution after the use of the post-processing tools and the newer *Deimos 4EO* software.
- **The spectral resolution at different bands:** panchromatic + RGB (red, green and blue) + Near-Infrared
- **The high accuracy technology:** Basically focused on the OCS technology, which is currently being under development by *Deimos Space* and that will allow to provide the image value-added service using the newer *Deimos 4EO* software.
- **The revisit time:** Which is expected to be less than two days.
- **The swath:** Having an expected field-of-view of 9.5 km.
- **The competitive price:** Which will allow to compete inside the market and engage new potential clients.

8.4.3 Channels

Since the *Deimos'* project requires a large investment, the satellite and its new technology would be highly advertised, with the objective of catching potential customers. Besides, it is important to consider that as the company already had a previous success, the recommendations that the new potential clients could receive of the company will also provoke a decisive impact on making a first contact.

This way, it is thought that the best idea to communicate the potential clients with the company would be to use a fluid and direct channel, using the *4EO* software for allowing the customer to directly interact with the satellite and analyse its images. This way, it is also considered that the developed software can also be used in order to make tutorials and provide examples of already post-processed images in order to convince the potential customers, allowing to clearly show them the different services that the company provides.

Finally, in order to close the deal, the *Deimos Space's* engineering team and sales force would communicate with the customers, through a direct channel, with the idea of defining the last details and complete the transaction.

8.4.4 Customer Relationships

The relationships with the customer would be based in five main points, which take into account all the information defined in the previous stages:

- **Customized service:** The ability of customising the service, allows to obtain an even more specialised service, according with the customer's needs.
- **VAS Customization:** Mainly it considers the value-added service (VAS) that has been previously defined and explained.
- **Quick team response:** Which allow to achieve an instantaneous answer to the issues that might appear. Besides, this point can be considered in all the project's steps, not only once the satellite has been launched.
- **Software licences (4EO software):** Basically, to keep buying images from the *sat4EO*, the client would need to have some software licences which can be renewed along the time. Moreover, the fact of using software licenses would allow to offer different type of licenses (with more or less accessories) accordingly with the client's needs and economic status.
- **Loyalty Bonus:** Similar with the previous point, it is considered that the potential clients may have some loyalty bonus and discounts in order to benefit and encourage the purchase of large amount of images.

8.4.5 Revenue Streams

As the final product that the service offers is the images that the *sat4EO* has taken, it is considered that the main company's revenue stream would be selling those images. Nevertheless, it is important to outline that other possible revenues can be found, dividing them in:

- **Sat4EO images sell:** The economic benefits achieved by selling the images to the customers. Basically is the bigger revenue stream source.
- **Patents utilization:** As the satellite will develop a brand new technology system which will be more accurate than the tools stablished now, it is highly possible than other competitors or research groups may wish to use the implemented technology implemented in the new *Deimos'* satellite, needing to pay for checking its patents.
- **4EO software licence:** As the clients will need subscribing to use the company's software in order to obtain the images and be directly connected with the satellites. Hence, as it was said in the previous chapter, the use of software licenses would allow to offer different type of licenses, increasing the possibilities of getting more economic revenues for this point.

Finally, it is important to highlight the fact that Ground Station Services may also be added, although this study is just focused on the satellite itself.

8.4.6 Key Resources

This way, three groups of resources are needed to carry out for the selling of the sat4EO images:

- **Physical:**
  - The **sat4EO platform** itself with its payload and its OCS system.
  - The **facilities, and the equipment** needed to control and monitor the satellite. Besides, this point must also consider the facilities and the equipment required to previously develop and produce the satellite.
- **Intellectual:**
  - This point includes the new technologies that are being developed by Deimos Space and its partners, which would be patented.
  - Of course, the **4EO software**, which is the main strength of the developed satellite.

- **Human:**
  - As the project that is being developed would be quite complex, Deimos Space will need to involve a **high-skilled staff** which will work in the project, in order to accomplish all the design, operation and post-process phases.

8.4.7 Key Activities

Hence, the activities that must be considered in order to obtain the *sat4EO* images, include.

- **The platform development:** That means the design, production, integration, verification, testing and launching of the satellite.
- **The platform operation:** Which is focused on controlling and managing the platform once it is at the orbit.
- **Data analysis:** Which involves all the process related with the software and the image post processed value-added service offered by the company.
- **Sales management:** Which considers all the marketing process and the main point of selling the images after they have been analysed and post-processed.

8.4.8 Key Partnerships

Moreover, the key partnerships that the *Deimos* will need to produce in order to develop the *sat4EO* project, are:

- **Optical payload manufacturers:** It seems logical to consider them as a main critical partner, because the final resolution of the optical system determines the final performance of the platform.
- **Components and subsystems suppliers:** In order to achieve all the required components for the production of the satellite, regarding to obtain them with a low cost.
- **Launching partners:** In order to book the launch and place the satellite in the desired orbit, as *Deimos* does not have an own launch facility.
- **Ground station partners:** In order to monitor and control the satellite.
- **Data management partners:** Which would facilitate a warehouse, the software development and the maintenance of the satellite's software.
- **Space agencies and governmental institutions:** Which would provide the necessary facilities, resources, knowledge and funds to develop the required technology for doing the project's mission.

8.4.9 Cost Structure

Finally, it is important to outline that the cost structure related to keep the *Deimos sat4EO* operating, would be the sum up of all the activities, resources and partnerships that the satellite requires. Hence, the list of items would be:

- 1. Launching costs:
- Facilities and equipment for the launch.
- Licences, taxes and insurance for doing the launch.
- Fuel and supplies.
- *Sat4EO* operation, monitoring and control until it is at the orbit.

- 2. Development costs:
- Facilities, equipment and resources for doing the R+D of the satellite, its tests and its development and construction.
- The R+D of the *4EO* brand new software and the post processing value added service.
- High-skilled staff salaries.
- Quality control.
- Licences, taxes and insurance for doing the tests.

- 3. Operational costs:
- Define the patents for the developed technology.
- Salaries of the salesforce and engineering team.
- Marketing costs of the company.
- Ground station maintenance.
- Software maintenance and update.

So, in order to conclude, all the building blocks developed for this company are summarized in the business model CANVAS of *figure 8.6*.

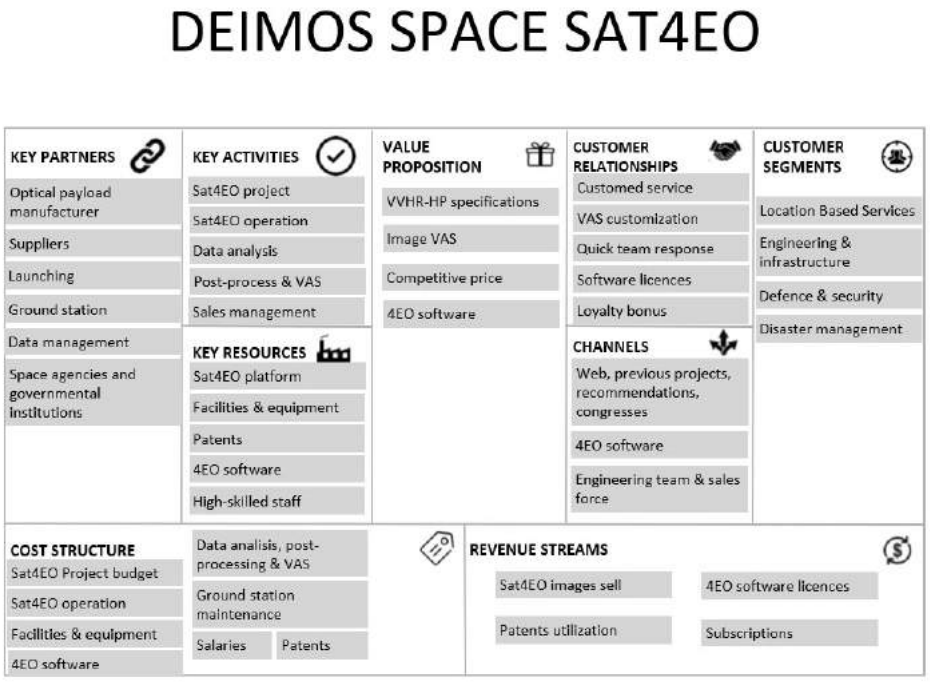

Figure 8.6: Business model canvas of Deimos sat4EO

9 Applying DISCOVERER solutions to the NEW CANVASes

9.1 Applying DISCOVERER technologies to new satellite solutions

This chapter will be focused on describing the *DISCOVERER's* findings in the technology area, which will provide some of the required VLEO satellite solutions. Moreover, it is important to state that the different items included in this section were obtained from various roadmaps included in [*TFE-17*], [*TFE-18*], [*TFE-19*] and [*TFE-20*].

9.1.1 Strengths and weaknesses of DISCOVERER technologies

The following analysis is performed using only the internal factors of the DISCOVERER project and taking into account the technological aspects. The DISCOVERER technologies are divided in three main groups, for which a summary is presented:

Table 9.1 Strengths and Weaknesses of the DISCOVERER technologies (extracted from D5.3 & D5.4)

	Strengths	Weaknesses
Atmosphere-Breathing Electric Propulsion [ABEP]	● Enables long term operation in VLEO (up to theoretically infinite): without ABEP some of those missions would not be possible. ● Potentially reduced launch costs as there is no propellant and tank required. ● Absence of propellant can compensate for ABEP system weight. ● Semi-controlled EoL re-entry possible. ● Enhanced environmental sustainability, compared with standard VLEO missions.	● ABEP technologies are currently in development. ● Limited altitude range of operation. ● System complexity may be increased (including intake). ● Possibly increased manufacturing costs. ● Increased spacecraft power requirement. ● Increased requirement for precise flow-pointing attitude.
Low drag, reduced erosion materials	● Specular or quasi-specular gas-surface interactions enable variation in aerodynamic behaviour based on geometry (i.e. surface incidence to the flow). ● Lower drag (for surfaces at low angle of incidence to the flow) reduces propulsive requirements and increases lifetime. ● Increased lift forces enable enhanced aerodynamic control. ● Increased drag (for surfaces at high angle of incidence to the flow) can contribute to end-of-life deorbit requirements. ● Materials with enhanced erosion and chemical degradation performance have been largely proven.	● Theoretical combined atomic oxygen and specular reflection properties have not yet been fully demonstrated in a relevant orbital environment. ● Possible increases in complexity, time and costs of surface coating, handling, and integration. ● Increased geometric and structure complexity to achieve low-drag benefits.
Orbit and Attitude aerodynamic control	● Takes advantage of the aerodynamic forces and torques. ● Improved satellite control and manoeuvrability. ● Can contribute to the reduction in requirements of traditional attitude and	● Still in early development stages and requires in-orbit demonstration. ● Requires specific design for different spacecraft geometries. ● Dependent on the performance of materials to produce aerodynamic

	orbit control systems with possible benefits to spacecraft mass and propellant requirement.	forces and torques. ● Fuel consumption depending on the flow alignment of the satellite.

9.1.2 System Integration and Benefits of DISCOVERER technologies

System modelling of the technologies developed within the scope of DISCOVERER has been reported in [RD-5.4] and a related paper [21]. In these documents, the system models for the technologies described are implemented within a conceptual design framework. The technologies are shown to have the potential to enable sustainable operations at these lower altitudes. However, given their low technology readiness level (TRL), there is currently insufficient data to forecast the exact benefits that can be provided and the overall system performance that can be achieved.

ABEP

The ongoing development of space propulsion systems is highly relevant to VLEO spacecraft. In particular, efficiency increases of propulsion systems will reduce the power and propellant requirements for drag compensation or mitigation. This way, the article outlines that:

- ABEP systems would enable theoretically sustainable operation in VLEO, limited only by component lifetime.
- Such concepts intend to use a forward-facing intake that collects propellant from the residual atmosphere and utilises it in an electric thruster, eliminating the need for the spacecraft to carry or be launched with any propellant.
- The development of ABEP systems is currently focused on the design of intakes that can efficiently collect the required propellant from the atmosphere under the free molecular flow conditions in VLEO and the development of electric thrusters that can flexibly utilise the range of different atmospheric gas constituents that will be collected and are resilient to erosion or degradation by the aggressive atmospheric components.
- Critical considerations for ABEP thruster development include compatibility and performance under the conditions of changing atmospheric density and composition, for example with the solar cycle or smaller shorter-term variations.
- Owing to the relative immaturity of these technologies, the efficiency of ABEP thrusters is currently lower than that of established electric propulsion types.

Electric Power System (EPS)

EPS architecture for VLEO satellites is likely to be similar to that of conventional orbiting platforms, using solar-arrays as the primary power source with supporting batteries to enable operations during eclipse periods. Nevertheless, the article states that:

- For VLEO satellites with ABEP for drag compensation or mitigation, power requirements are likely to be significantly increased.
- For solar-based power the implication on spacecraft aerodynamics (principally drag) and stability due to the presence of extensive solar arrays must also be carefully considered and captured in the aerodynamic models.

So, given challenges and the high requirements for EPS design in VLEO, the system performance is therefore critical. Consequently, high efficiency solar cells will help to reduce the solar array area and therefore reduce contributions to aerodynamic drag and therefore propulsive requirements. Finally, high specific power of solar arrays and increased energy density of batteries will also contribute to a reduction in system mass.

Aerodynamic attitude and orbit control methods

Methods of aerodynamic orbit control that utilise aerodynamic forces and torques to modify the orbital parameters of a satellite or the relative motion between multiple satellites are also being developed. Hence, the article depicts that:

- Aerodynamics-based attitude control methods include pointing and momentum management manoeuvres that can assist and reduce the requirements on traditional attitude actuators.
- Aerodynamic attitude control can principally be implemented through the use of external control surfaces, though manipulation of the centre of mass may also be used to implement some control of generated aerodynamic torques.
- Aerodynamic trim manoeuvres can also be considered to directly reject external disturbances, for example as a result of variations in the oncoming own direction, solar radiation pressure, and residual magnetic dipole interactions.
- Proposals for orbit control include constellation deployment, formation keeping rendezvous, inclination correction for sun-synchronous orbits, and atmospheric re-entry interface targeting.

System-Level Trade-Offs

In summary, the use of both EP and ABEP for drag compensation has been shown to enable operations in significantly lower altitudes than current commercial EO spacecraft. The benefit to payload design at these lower altitudes principally results in a significant reduction in the total system mass, particularly for optical observation instruments, though this is bounded at very low altitudes by the increasing atmospheric density and drag. The use of drag-reducing materials, enhanced electrical power systems, and increased propulsive efficiency further increase the system performance and enable further reductions in orbital altitude, resulting in spacecraft of even lower mass. This reduction in system mass was also found to correspondingly reduce the system development and manufacture costs, though current cost-estimating relationships were found to be ill-suited for modelling aspects of the novel technologies.

9.2 EO Platform Concepts

As it was seen in *section 8*, the platforms play and important role inside the *DISCOVERER's* goals. Thus, it is important to analyse them, considering the fact that the **main EO platforms system concepts for VLEO applications** are [19]:

- Very High Resolution - High Performance (VHR - HP).
- Very High Resolution - Low Cost (VHR-LC).
- Global coverage.
- Synthetic Aperture Radar Optic (SAROptic).

This way, the first three platforms technologies of the previous list can be classified as passive sensors, while the last one is an active sensor (SAR). It is important to consider that the Coverage and the VHR-LC platforms have been combined into the VHR-LC / Constellation platform. Therefore, we will just focus on three concepts: *VHR-HP, SAROptic and VHR-LC Constellations*.

Firstly, taking a closer look at the **VHR-HP platform technology**, the corresponding GSD of these optical sensors is lower than a meter. Particularly, the optimal resolution commercially available is less than 30cm, which is considered within this platform. Even though, in some countries, it is illegal for commercial purposes to sell imagery with a resolution lower than 50 cm. Due to this restriction, a suitable application for this platform is the defence market, but it will not be considered as only civil applications for the EO satellites are being considered in this project. Besides, some other potential customers are the disaster management sector and the infrastructure market, among others.

Secondly, the **VHR-LC platform technology** has a spatial resolution between 1 and 5 meters (GSD). This type of platform aims to offer extensive coverage of high-resolution imagery at a lower price. Thanks to the use of a satellite constellation the revisit time can be reduced and the collection capacity can be improved, without highly increasing the selling price of the images. Also, the data transmission problem, typical of VLEO, can be reduced. Therefore, the solution of using a small satellites constellation has become more popular, because it is less expensive and more reliable than a single satellite.

Third and according to the ESA's website [20], [22] the **active SAR instrumentation** transmits electromagnetic pulses to the Earth's surface provoking that the onboard system receives then the

backscattering echoes from the ground. Subsequently, the received echoes are transformed into baseband and digitised, calling it Raw Data which is stored in Solid State Mass Memories for a short period, till it is sent to Earth. Finally, once the data has arrived at the ground facility, it is processed by small blocks (due to the memory issues) in range (horizontal) direction and then in azimuth or flight (vertical) direction, obtaining as a result big images or an image mosaic.

It is important to outline that since this technology is an active sensor, it has the main advantage that it still works in cloudy areas or dark conditions. Thanks to that, the SAR instrument can constantly acquire samples under any meteorological conditions [20].

9.3 Case Studies

So, taking a closer look at the operators that are willing to exploit the VLEO for EO, three companies which use the considered platform technologies, are going to be presented:

9.3.1 Planet Labs (VHR-LC/Constellation platform):

Planet Labs is an American company whose goal is to image the entire Earth daily and make global change visible, accessible, and actionable [23]. In this company, the imagery and the global coverage is obtained by optical constellations at VLEO, being the *PlanetScope* constellation the case study considered for the VHR-LC Constellations platform.

This constellation consists of more than 130 satellites (called Doves) whose characteristics are summarised in *table 9.2* extracted from [23]:

Table 9.1 Summary of the technical characteristics of the Doves satellites [23]

Doves overview	
Altitude	475 km
Satellite typology	3U Cubesat
Weight	5 kg
Dimensions	10x10x30 cm
Resolution (GSD)	3.7 m
Spectral resolution	4 wavebands

On the other hand, regarding the whole constellation, the revisit time is daily at nadir, and the imagery collection capacity is of 200M km^2 per day [24].

Lastly, the *Planet* company is focused on analytical products for change detection, rather than the raw image [19]. Particularly, the firm principally focuses on giving insight to the following industries: Agriculture, Education and Research, Energy & Infrastructure, Forestry & Land Use, Government, Finance & Insurance, Mapping, Maritime, Planet Federal and Sustainability [23].

9.3.2 Sat4EO by Deimos (VHR-HP platform):

The *Deimos Space project Sat4EO* is a satellite programme that aims to ensure cost-efficient VHR imagery [25] by using VHR-HP satellites. It is important to outline that it is still in developing terms. Therefore, the mission specifications and the characteristics presented in [*TFE-13*] are still preliminary:

- Sun-synchronous orbit with an altitude between 450 and 500 km.
- The *Sat4EO* is expected to measure 1x1x1.5 m, weighs 225 kg and its expected lifespan is 4 years.

- Spatial resolution: 0.3 m final GSD.
- Passive sensors: multi-spectral and panchromatic (resulting imagery is pan-sharpened).
- Temporal resolution: approximately less than 2 days.
- Geometric resolution: a swath of 9.5 km.

Two Main hypothetical options are being studied:

- To produce the satellite and sell it to a private company. Thus, the main potential customers would be governments and companies that already operate EO satellites but want to acquire new ones with better resolution.
- To become a vertically integrated company which operates their satellites and then sells the processed images. In this case, the potential clients will be big companies or individuals for defence, disaster management, and engineering projects, among others.

9.3.3 Satellogic (SAROptic):

Satellogic is an Argentinian company that offers geospatial insights for various industries, such as agriculture and forestry [25]. In this case, the company uses its SAROptic satellites constellation to obtain an up-to-date picture of the Earth and to provide affordable, high-resolution geospatial imagery and analytics. Furthermore, thanks to the use of the SAROptic system, an uninterrupted coverage can be ensured [25].

Moreover, the total number of in-orbit satellites dedicated to delivering high-resolution data that Satellogic possesses is 14. Thus, Satellogic becomes the EO company which has more in-orbit capacity for high-resolution imagery.

Therefore, the improved specifications [25], [26], [27] of the constellation are:

- HP Earth imagery (0.7m resolution).
- Complete AOI remap every 4 weeks.
- Revisit a specific point of interest up to 4 times per day.
- Three different cameras: multi-spectral, hyper-spectral and SAROptic. Adding, this way, a dimension beyond the visible spectrum of the geospatial data.
- Constellation's collection capacity of 4M km^2/day.
- Register, flag and regulate the satellites.

It is important to state that these new characteristics will not be available until the recently launched satellites are completely positioned and fully calibrated, which is expected to happen at the beginning of 2021.

Considering these characteristics, the *Satellogic* company also offers data analysis to develop VAS related to the obtained imagery. As well, this company counts with dedicated ground facilities. The main purposes and characteristics of these down on Earth facilities are to develop direct tasking from their own Ground Station, to ensure a secure and encrypted end-to-end data download, and that only the operating entity knows the tasked AOI and the obtained data [25].

Finally, the leading customers that this company is focusing on are: Forestry, Agriculture, Energy, Finance & Insurance, Cartography, Critical Infrastructure Management, and Environment [25].

To conclude the section, in *table 9.3* the three case studies are summarised. The items considered are the number of satellites that form each constellation, their orbit's altitude, the spatial resolution (GSD), the imagery collection capacity per day, the revisit time per day and the type of sensor used.

Table 9.2 Summary of the technical characteristics of the three Case Studies

Company	Country	Satellite name	Constellation name	Nº of satellites	Altitude (km)	GSD (m)	Collection capacity (km^2/day)	Revisit time (days)	Type of sensor
Planet Labs	USA	Dove	PlanetScope	130	475	3.7	200 M	1	Passive
Satellogic	Argentina	N/A	Aleph-1	14	475	0.7	4 M	0.25	Active & Passive
Deimos Space	Spain	Sat4EO	N/A	N/A	450-500	0.3	57.600 (per satellite)	<2	Passive

9.4 Business Model Value Proposition CANVASes

The following section will present the proposed Value proposition CANVASes for the three previous case studies once applying the *DISCOVERER* technologies. In this analysis, the final product considered is the imagery gathered by each platform. Also, three existing Business Models will be presented highlighting the variations due to the use of these new technologies.

9.4.1 Business Model for a VHR-LC Constellation Platform

It is important to remember that the final offered product is the processed imagery and data obtained by the constellation.

PERSONA PROFILE

Nowadays, according to *Planet's* website [23], the main customers that buy imagery gathered by the *PlanetScope* constellation belong to the following industries:

- Agriculture.
- Education & research.
- Forest & land use.
- Maritime.

Specifically, in this analysis the client studied belongs to the maritime industry, needing new ways of surveillance overseas areas or to track their vessels. Also, with the *PlanetScope* products, they are able to identify vessels and objects, monitor coastlines and ports, and identify oil spillage, among other options [23].

Hence, the persona profile would be a customer willing to acquire monitoring data of overseas areas. Particularly, maritime ships detection in coastline areas, open waters imagery to see vessels activity, and tracking the company's vessels. This customer will prioritise cost over resolution.

CUSTOMER PROFILE

Once the buyer persona is defined, the next step is to define the customer profile, which consists of the buyer's jobs, pains and gains presented:

- **Jobs**
    - Processed: acquiring the already processed data to monitor the vessels, track the activity in coastlines or open waters, among others.
    - VHR (3.7m): imagery with enough resolution to correctly identify vessels or other objects, as well as, identify for instance offshore oil rigs.
    - Tracking: acquiring data on the location of the company's vessels and being able to take a look at certain marine areas.

- **Pains**
  - Bad integration: the acquired imagery cannot be correctly integrated into the used applications or work programmes.
  - Not updated: the received data is not current or not completely up-to-date.
  - Expensive: the costs of acquiring these products are higher than what can be afforded or not enough profitable.
- **Gains**
  - Adaptability: paying just for the wanted services or products.
  - Innovation: the hired services are not traditional but improve the company's performance, which causes a reduction in costs.
  - Strategy: the acquired data gives daily information about open waters areas, which helps to develop strategies to prevent risks or improve the vessels routes.
  - Historical data: access to older imagery to see the changes in some marine areas, such as climate change effects or how an oil spill affected an area.

VALUE MAP

This side of the CANVAS is formed by the products & services, the pain relievers, and the gain creators. Each one of these items is linked to the customer's profile jobs, pains and gains respectively. Hence, the Value Map is presented in *table 9.4*.

Table 9.3 VHR-LC Constellation Value Map

VHR-LC Constellation Value Proposition CANVAS - Value Map		
Customer link	**Products & Services**	**Description**
Processed	Usability	Offer easy access to the acquired imagery and analysed data. Also, provide the customer with the necessary tools.
VHR	Optical equipment	Resolution of 3.7 m
	DISCOVERER technologies	The use of new materials may help to reduce the orbital altitude whilst still providing a useful lifetime without propulsion.
Tracking	Geolocation	Upgrades in the satellites to geolocate vessels in open waters within an acceptable error.
	DISCOVERER technologies	The use of these technologies improves the satellite's accuracy (ABEP and Aerodynamic Controls) and extends the lifetime of the mission.
Customer link	**Pain relievers**	**Description**
Bad integration	Personalization	Easily integrate the imagery to the customer's company application or format.
Not updated	Revisit time	Short revisit time due to the constellation, which allows almost daily imagery updates.
	Constellation	Thanks to the high number of satellites, the collection capacity is higher and also the data transmission is improved.
	DISCOVERER technologies	These technologies help to maintain the optimised orbit and slightly manoeuvring the satellite if needed (ABEP and Aerodynamic Controls).

Expensive	Democratisation of space	Keep the prices affordable and cheaper than traditional.
	DISCOVERER technologies	Thanks to the application of these technologies the mission's costs can be reduced and more revenues can be provided due to the extended life time.
Customer link	**Gain creators**	**Description**
Adaptability	Customisation	*Planet* offers different products or services.
Innovation	Newness	*Planet* offers a revolutionary product as well as a non-traditional service.
	DISCOVERER programme	This programme researches new technologies that can enable and improve the VLEO satellites.
Strategy	Risk reduction	Thanks to the *Planet's* products certain open water areas can be daily surveilled.
Historical data	Planet's archive	The customer has access to the imagery archive

Once the different profiles and the Value Map are presented, the last step is to graphically represent all the previous information into the **Value proposition CANVAS**. Therefore, the following figure (*figure 9.1*) shows the CANVAS for a possible buyer of the imagery gathered by the *PlanetScope* constellation applying the DISCOVERER technologies.

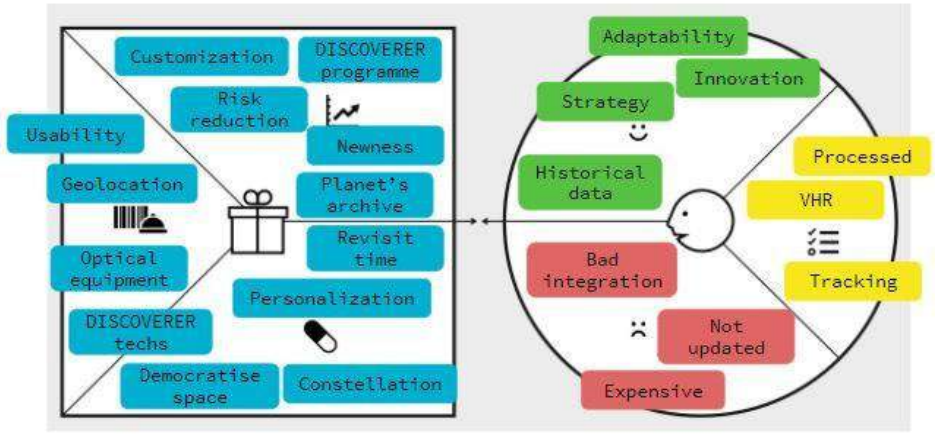

Figure 9.1: Value Proposition of VHR-LC Constellation CANVAS

AD-LIB

To summarise the proposed value proposition, it is expressed following the Ad-Lib template. Particularly, the aspects in which the DISCOVERER technologies have an important effect are highlighted in blue.

"Our PlanetScope imagery helps private firms who want to improve their company's performance by acquiring great resolution imagery at low cost and adding new monitoring and management systems."

ENHANCED CANVAS BUSINESS MODEL

Once the value proposition is developed, the summarised **enhanced CANVAS Business Model for Planet** is presented in *figure 9.2*. It is important to outline that some of the information is obtained from [28], being similar to the CANVAS business model presented in *section 6.1*. Although as this section considers the DISCOVERER technologies analysis, thus some points differ from *figure 6.1*.

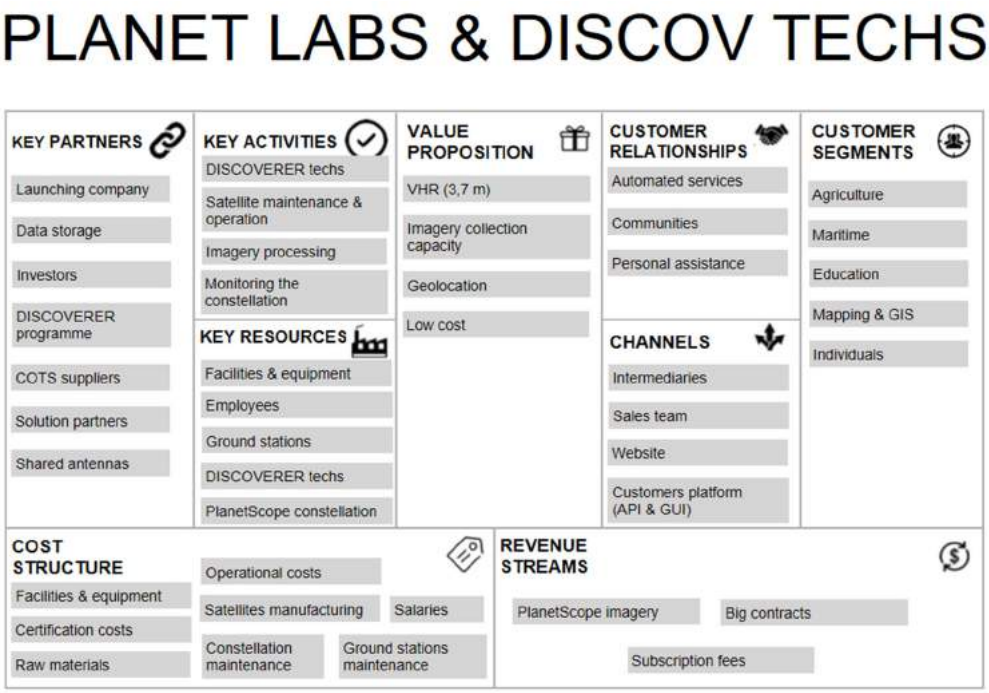

Figure 9.2: Business model CANVAS of VHR-LC Constellation including DISCOVERER improvements

9.4.2 Business Model for a VHR-HP Platform

It is important to outline that the information analysed in order to develop the CANVAS Business Model, was obtained from [*TFE-13*].

Moreover, it is expected that most of the potential customers will belong to big companies which develop engineering projects, due to the fact that they can raise higher investments in order to afford a VHR imagery system. For instance, companies needing LBS or processed imagery of a certain AOI, among other products.

PERSONA PROFILE

Therefore, the persona profile would be a client willing to acquire processed images and data of a certain AOI or of a particular topic. Usually, the needed imagery is of urban areas or big cities. Lastly, this customer will prioritise resolution over cost.

CUSTOMER PROFILE

This side of the CANVAS is formed by the categories defined in the following lists.

- **Jobs**
    - Processing: acquiring processed images which are ready to extract all the needed information.
    - Analysing: along with the imagery, acquire the necessary data already analysed and ready to use.
    - VVHR (<30cm): the acquired imagery has the best resolution possible which helps to correctly identify all the wanted items.

- Accuracy: acquire images of a particular area of interest or gather data of a certain topic.

- **Pains**
  - Lack of data: not enough images or data in order to correctly develop the project.
  - Inoperative: the acquired data does not fit with how the company works or how the data is managed.
  - Not high-end technology: the images are obtained or processed by obsolete or not state of the art technologies or equipment.
  - Overpriced: paying for services that are unnecessary or the prices are too expensive for the offered products.

- **Gains**
  - Sized services: pay just for the services needed.
  - Updated: periodically acquiring new images of the AOI or about a certain topic.
  - Problems solving: customer's assistance whenever necessary and easy to access.
  - Improvement: the best possible product is the one acquired.

VALUE MAP

In *table 9.5*, the three items of the value map are presented, as well as their corresponding customer profile item:

Table 9.4 VHR-HP Value Map

VVHR-HP Value Proposition CANVAS - Value Map		
Customer link	**Products & Services**	**Description**
Processing	VAS	Value added services for processing the raw images.
Analysing	VAS	Value added services for analysing the data gathered by the satellite and obtain the needed information.
VVHR	Optical payload	The payload is an optical sensor with a resolution of 0.3 m
	DISCOVERER technologies	The materials and ABEP allow sustained operation at a lower orbital altitude. Therefore the payload and satellite can achieve the VVHR performance with a smaller mass and volume.
Accuracy	Orbit	The mission is designed in order to target the wanted AOI.
	DISCOVERER technologies	The use of these technologies helps the satellite to maintain the orbit for a longer period and also the satellite is able to better target the AOI.
	OCS technology	Operational control system developed by *Elecnor Deimos*.
Customer link	**Pain relievers**	**Description**
Lack of data	Deimos archive	Possibility of accessing the Deimos imagery archive.
	Revisit time	As the satellite is located at VLEO, the short revisit time helps to target more often a certain AOI.
	DISCOVERER technologies	Thanks to the application of these technologies the satellite may have a better performance in terms of overall transmission and reception of data.
Inoperative	Personalization	Adapt the information format transference in order to fit with the

		customer's format.
Not high-end technology	New technologies	Using the best technology available and updating the equipment when necessary.
Overpriced	Options	The option of choosing and paying only for the services wanted.
	DISCOVERER technologies	Due to the application of these technologies, the overall mission costs can be lower than a repeated satellite substitution along time, leading to more competitive prices.
Customer link	**Gain creators**	**Description**
Sized service	Customisation	The customer just pays for the needed VAS.
Updated	Revisit time	As the satellite is located at VLEO, the revisit time is longer, and the time the satellite is targeting the desired point is shorter.
	DISCOVERER technologies	Due to the use of ABEP and Aerodynamic Controls the satellite targets better the AOI as well as it can maintain the optimised orbit for a longer period. Also, these technologies improve the data transmission.
Problems solving	Interface	Customer's assistance via software and via a platform designed by *Deimos*.
Improvement	Up-to-date	The *Sat4EO* programme staff keeps researching as well as some of the partners.
	DISCOVERER programme	The DISCOVERER project aims at research in brand new technologies that will be applied to VLEO satellites.

Once that the different profiles and the Value Map are presented, the last step is to graphically represent all the previous information into the Value proposition CANVAS. Therefore, *figure 9.3* shows the CANVAS for a possible client of the imagery gathered by the *Sat4EO* satellite applying the DISCOVERER technologies.

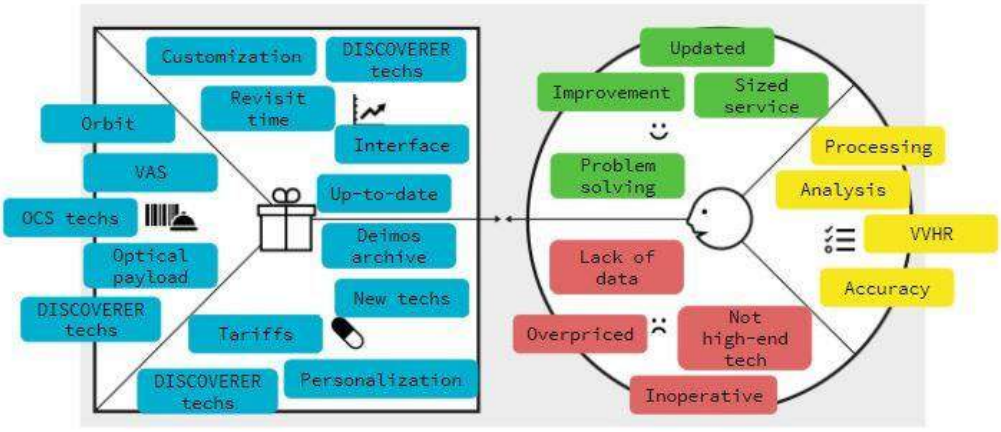

Figure 9.3: Value Proposition of VHR-LC Constellation CANVAS

AD-LIB

The aspects in which the DISCOVERER technologies have an important role are highlighted in blue.

"***Our Sat4EO imagery helps big data companies who want to improve the post-process of the acquired images by avoiding lack of data and promoting sized services at competitive prices.***"

ENHANCED CANVAS BUSINESS MODEL

Once the value proposition is developed, the summarised **enhanced CANVAS Business Model for Sat4EO** is presented. It is important to outline that some of the information is obtained from [*TFE-13*], considering only the DISCOVERER technologies, not the whole *Deimos Space* company. Thus, the presented CANVAS differs from the one presented in *figure 6.5*.

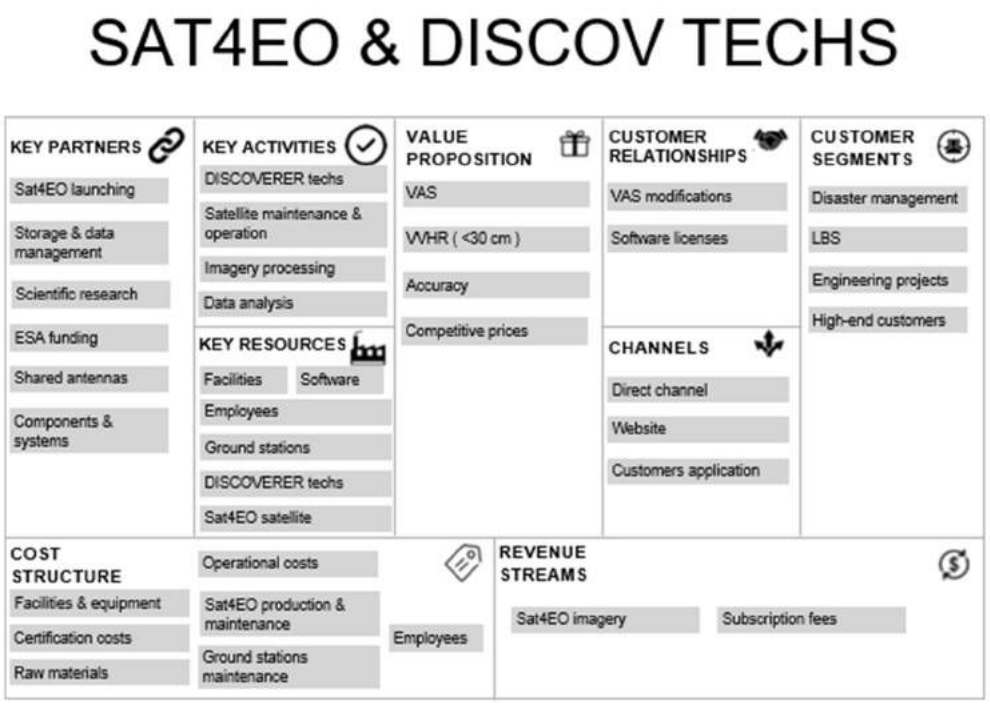

Figure 9.4: Business model CANVAS of VHR-HP including DISCOVERER improvements

9.4.3 Business Model for a SAROptic platform

Emphasise that the final product offered by the company is the processed images gathered by the constellation. Consequently, the Value proposition CANVAS which considers the DISCOVERER technologies is presented:

PERSONA PROFILE

According to *Satellogic's* website [25], the main customers of the company belong to the following industries:

- Agriculture.
- Energy.
- Forestry.

For this specific study, the considered client belongs to a forestry company whose woodlands are located in a country near the North Pole (few sunlight hours) or with a rainy climate (many cloudy days), such as Ireland or Norway.

Moreover, it may need insights for optimising woodland management or stopping illegal harvesting on their forest lands. Additionally, thanks to the *SAROptic* satellites, the company may be able to estimate current forest-stand variables, such as height, volume, and basal area [25], as well as mapping water bodies or testing inundation models [28].

Therefore, the persona profile would be a client willing to acquire processed imagery and data of the company's forest land. Particularly, the customer wants to prevent theft, track the evolution of the vegetation and map near floods, among others.

CUSTOMER PROFILE

In this case, the items analysed are:

- **Jobs**
  - Treated: acquiring the processed imagery in order to obtain the necessary parameters of the owned forest lands.
  - Accuracy: images and data of the company's woodlands and the areas surrounding them.
  - Specificity: the products and services hired gather the wanted information and the necessary specific data.
- **Pains**
  - Delayed: the received data is not updated.
  - Weather conditions: not being able to receive imagery or data during cloudy days or bad weather conditions.
  - Too expensive: the products are overpriced or not profitable enough for the company.
- **Gains**
  - Resolution: acquiring imagery with great resolution, which helps to correctly identify the necessary forest-stand variables.
  - Success rate: being confident of receiving the data when agreed and of being notified when illegal harvesting occurs.
  - Risk prevention: being able to acquire flood mapping if needed.
  - Enhancement: the hired company keeps improving their equipment in order to optimise expenses.

VALUE MAP

In Table 9.6, the items of the value map are presented, as well as their corresponding customer profile item.

Table 9.5 SAROptic Value Map

SAROptic Value Proposition CANVAS - Value Map		
Customer link	**Products & Services**	**Description**
Treated	Machine learning	Due to the use of machine learning algorithms the imagery can be processed to obtain the wanted data.
Accuracy	Constellation	Thanks to the constellation the imagery collection capacity is increased, which also helps to target the AOI.
	DISCOVERER technologies	The use of ABEP and Aerodynamic Controls can enable the maintenance of the satellites in the optimised orbit and, if needed, slightly manoeuvring can be performed.
Specificity	Information	The satellites and the post-processing process can gather the specific data needed by the forestry company.
Customer link	**Pain relievers**	**Description**
Delayed	Revisit time	The satellite constellations located at VLEO can reduce the revisit time, allowing Earth data collection up to four daily revisits of a certain AOI.
	Constellation	Even though it is a small constellation, it improves the data transmission and the imagery collection capacity.

	DISCOVERER technologies	The application of these technologies, added to the use of constellations, improves the satellites' performance in terms of transmission and precision, among others.
Weather Conditions	SAROptic	The SAR camera can gather imagery regardless of the weather conditions or the day/night cycle.
Too expensive	Democratisation of EO	*Satellogic* offers competitive prices.
	DISCOVERER technologies	Thanks to the application of these technologies the mission's expenses are reduced.
Customer link	**Gain creators**	**Description**
Resolution	SAROptic	This combined camera ensures a great resolution (1 m).
	DISCOVERER technologies	Due to the use of new materials the sensor remains in good conditions for a longer period of time.
Success rate	SAROptic	This sensor allows to gather imagery even though it's a cloudy day or during no sunlight hours.
Risk prevention	SAROptic	Some of the applications of this sensor is flood mapping or testing inundation models.
Enhancement	Research	*Satellogic* continues to research and test new technologies.
	DISCOVERER programme	This programme researches to achieve new technologies that will improve the VLEO satellites.

VALUE PROPOSITION CANVAS

Therefore, the *figure 9.5* presents the filled CANVAS for the potential buyer of the imagery gathered by the *Satellogic* constellation (SAROptic) applying all the DISCOVERER technologies.

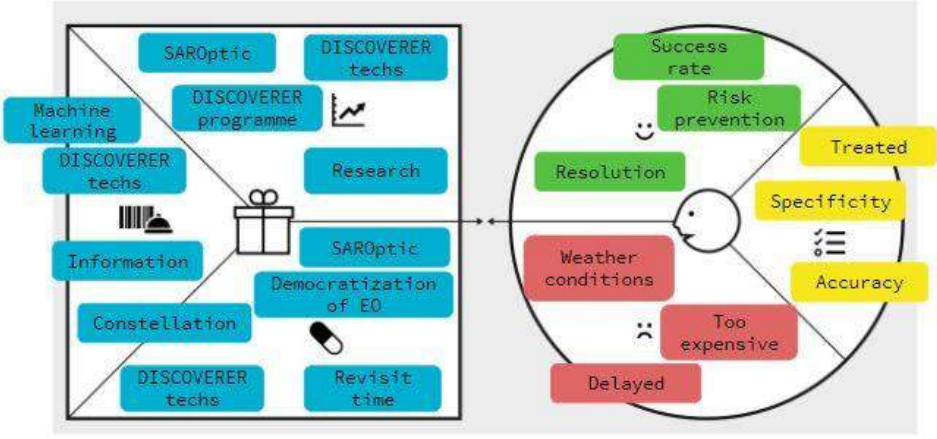

Figure 9.5: Value Proposition of SAROptic Constellation CANVAS

AD-LIB

The Value proposition CANVAS is summarised using the Ad-Lib template. In this case, the features in which the DISCOVERER technologies play an important role are highlighted in blue.

"***Our SAROptic imagery helps commercial companies who want to acquire specific information by gathering the necessary data regardless the weather conditions and improving the risk prevention while maintaining competitive prices* ".**

ENHANCED CANVAS BUSINESS MODEL

Once the value proposition is defined, the summarised **enhanced CANVAS Business Model for Satellogic** is presented. It is important to outline that some of the information is obtained from [17], considering only the DISCOVERER technologies. Thus, the presented CANVAS differs from the one presented in figure 6.4.

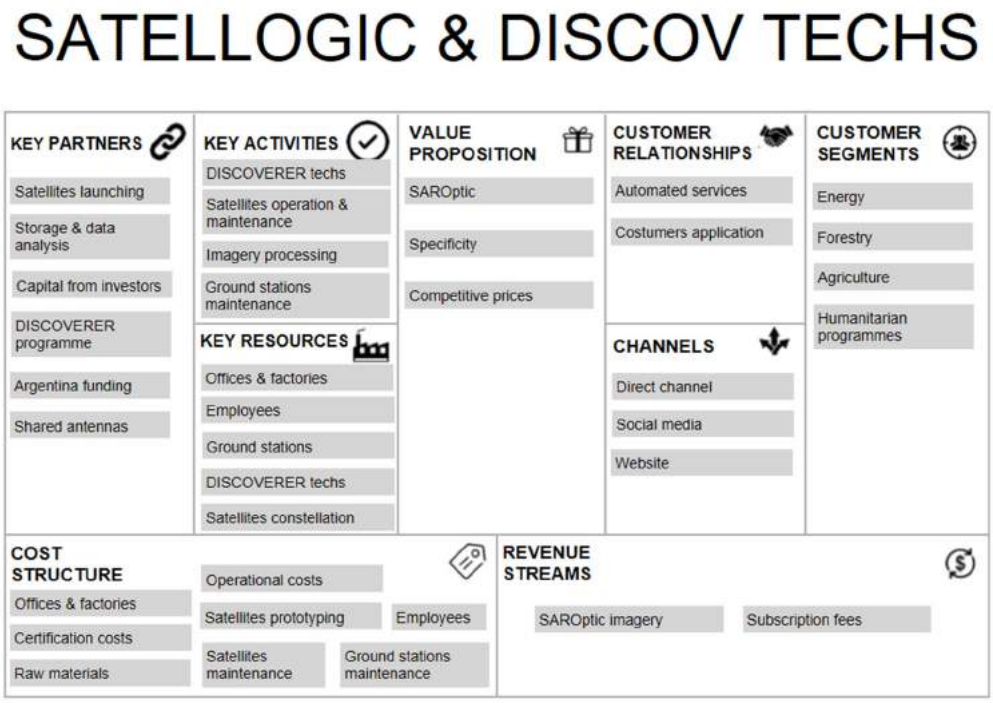

Figure 9.6: Business model of SAROptic CANVAS including DISCOVERER improvements

10 Conclusions/recommendations

This document deepens the work performed along the whole WorkPackage WP5, combining and enhancing the results of the previous Deliverables:

- D5.1 – EO market overview.
- D5.2 – Benefits and applications of VLEO for EO.
- D5.3 – EP market assessment.
- D5.4 – System models of VLEO platforms.

into a set of new Business Models plus some proposal of variation of other existing BM for EO applications.

The existing BM of some of the most representative companies in EO applications have been deeply analysed (*chapter 6*) in order to identify the success factors and patterns that can be extrapolated into the expected new BM. One of the findings after this analysis is a new common pattern "Democratizing Pattern" (*chapter 7*) that is also being implemented in the design of the new BM.

As a result of that, the following BM covering the whole range of identified opportunities of the EO market at VLEO can be found in *chapters 6 and 8*:

- BM for access to space companies.
- BM for new opportunities in the ground segment services.
- BM for space brokers.
- BM for new VHR-HP platforms.
- BM for VHR-LC constellations.
- BM for SAR platforms.

Besides that, in *chapter 9*, the BM for the space segment, are also analysed through the Value Proposition CANVAS (VPC) in order to identify how some of the existing BM can take advantage of the DISCOVERER findings:

- VPC for new VHR-HP platforms, plus DISCOVERER technologies.
- VPC for new VHR-LC constellations, plus DISCOVERER technologies.
- VPC for new SAR platforms, plus DISCOVERER technologies.

The obtained results, combined with the results of other Deliverables of the technological WorkPackages, will be exploited in order to produce two new deliverables:

- D5.6 → Roadmap for the implementation of the DISCOVERER technologies.
- D5.7 → Roadmap for the implementation of the new BM for EO at VLEO.

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Ref.	Document Title	Version, Date	Type of document
RD-5.1	DISCOVERER-D5.1 - EO Market Overview	11, 21/03/2018	Public
RD-5.2	DISCOVERER-D5.2 - Benefits and Applications of VLEO for EO	01, 30/01/2018	Public
RD-5.3	DISCOVERER-D5.3 - Analysis of New Stakeholders in the VLEO Market	06, 07/05/2020	Confidential
RD-5.4	DISCOVERER-D5.4 - System Models Description of	01, 21/07/2020	Confidential

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APPENDIX D5.5 – Case Studies of successful companies

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Appendix A: Case Study - Planet Labs

This appendix will present the Case Study of Planet Labs. Planet Labs is an Earth Observation company, owner and developer of multiple Small Sats constellations, used for Earth Observation purposes. Besides this manufacturing tasks, this company also undertakes tasks related to image processing and geospatial intelligence and solutions development. This chapter is divided into History and Overview of the company (section A.1), Business Statement and Philosophy (section A.2), Ownership and Employees (section A.3), Partnerships (section A.4), EO Market Segment and Requirements (section A.5), Applications and Payload (section A.6), Production System (section A.7), Operations (section A.8), Online Platform (section A.9) and Financial Status and Risks (section A.10).

A.1 History and Company Overview

Planet Labs was officially founded in December 2010 under the name of Cosmogia Inc.[1]. But its history begins some years before when the founders, three young NASA scientists, met at the United Nations trying to find a way to use space to help people around the planet, protect biospheres and stop deforestation [2].

They were Robbie Schingler (MBA from Georgetown University, Master of Space Studies from the International Space University and BSC in Engineering Physics from Santa Clara University), Will Marshall (PhD in Physics from the University of Oxford, MSc in Physics with Space Science and Technology from the University of Leicester) and Chris Boshuizen (PhD in Physics from the University of Sydney). They came from three different continents, but they realised they shared a feeling of disillusionment with the established space industry. Specifically, with how it had become trapped in a tradition of requirements-driven approaches to design and testing, because that was leading to increasingly unaffordable spacecraft in terms of cost, mass and schedule [3].

Marshall, Boshuizen and Schingler had long wanted to change the space industry [4]. They just had not found how to do it yet, and probably needed to find whom to do it with. It was the early 2000s when they met at an international conference held at the United Nations aimed at young professionals to make policy recommendations on how space could benefit humanity [5]. That event would bond them to a global community of scientists and led to a relationship of regular collaboration over the next decade. Together, they wrote a paper for the European Union about space policy. It was a statement that they decided to join efforts to put together a report at a conference where no one was willing to put individual merits aside in the interest of making a higher contribution. That collaboration across different time zones required many phone calls at inconvenient hours but gained them a valuable experience in making big, international projects happen [4].

Sometime afterwards the three of them were working on small scientific satellites at NASA Ames Research Centre [6]. There, Engineering Director Pete Klupar would often hold his Blackberry in his hand and ask his staff why satellites were so expensive and carried outdated technology. “My smartphone is better than your spacecraft”, he used to say [7]. After hearing this a few times, Chris Boshuizen and Will Marshall realised how smart that thought was.

This was exactly the idea behind PhoneSat, a NASA project devised by Boshuizen and Marshall that put a mobile phone with extra batteries aboard three CubeSats to be launched in 2013. Again, by that time the two of them, together with Schingler, would have already left NASA to found their own start-up [7].

In 2005 they started living in a house together and, in what today would be considered a typical Silicon-Valley style, turned their garage into a workshop where they spent the weekends playing with satellite technology. When it got more serious, they started hiring friends. Eventually, they decided to leave the space agency. It was in that garage that they built their first satellite, called Dove. While it has become quite standard now for start-ups to start in a Silicon Valley garage, they proudly claim to be the first ones to literally build a satellite in such place [2].

In February 2012 the start-up moved into the SoMa coworking space in the trendy South of Market neighbourhood in San Francisco, where it remains today [4]. Other than its premises in the US (San

Francisco and Mountain View in California, and Seattle in Washington), it has offices in Amsterdam and Berlin. From there, its imagery is delivered to an International network of customers and partners in over 100 countries.

Reinventing space business is not easy, but Planet Labs has been quite consistent in its announced launch program. It launched its first satellites in 2013 [8]. Two years later, in July 2015, the company announced its future acquisition of BlackBridge and its RapidEye 5-satellite constellation, together with an archive of 6 billion square kilometres of imagery captured over the previous years.

By the time that acquisition was complete in October 2015 [8]—five years after being founded—Planet Labs was already operating the largest constellation of Earth-imaging satellites ever. Only months after, the corporation signed an introductory contract with the NGA (National Geospatial-Intelligence Agency), the largest of geospatial customers [9].

The business has kept expanding at a fast pace since early 2017. After hitting the headlines with their record-breaking launch of 88 nanosatellites on February 15 and bringing the constellation of Doves to 144, on April 19, 2017 the company announced it had completed the acquisition of Terra Bella, a rival satellite imaging company. It also confirmed that, as part of the deal, Google was now a noteworthy shareholder in the firm. Google had previously purchased Terra Bella (formerly named Skybox Imaging) in 2014 for an estimated price of $500 million [10]. In 2017 both Planet and Google were declining to disclose any other details about the deal other than the fact that Google had then a deal for some years to buy imagery from Planet [11]. Though Planet acquired Terra Bella business and satellites, the search engine giant would keep on licensing the satellite imagery for its mapping products such as Google Maps, so it would still keep control over the satellite imaging company [10].

By the end of 2017, Planet announced the accomplishment of its Mission 1 phase, which consisted in assembling a solid constellation of satellites (both its owned Doves and the acquired TerraBella and RapidEye constellations) ensuring daily global imagery coverage, at a wide range of resolutions.

After completing this first phase, Planet announced that it was entering its Mission 2 phase, which will expand the company towards research fields which involve Machine Learning procedures to process their imagery data, as well as creating the Queryable Earth project, focused on creating a daily updated index of all parameters on Earth’s surface by means of satellite imagery and Machine Learning and Artificial Intelligence methods. And finally, expanding the observation tasks towards the observation of the entire Solar System, through a collaboration with SpaceX to develop *Megasatellites* and *Megalaunchers*. As part of this second stage in the evolution of the company, in 2018 Planet acquired Boundless, a company devote to the development of Machine Learning methods.

A.2 Company Business Statement and Philosophy

Planet's goal is to use space to help life [12]. The Planet Code of Ethics, a means to put Planet's Company Values into practice, is shared on its website. The priorities mentioned are:

- Anti-corruption
- Follow international laws regarding global trade
- Preserve data privacy and confidentiality
- Maintain a positive work environment
- Perform a fair competition towards competitors
- Hire based on merits
- Avoid conflicts of interest
- Protect intellectual property
- Have a global positive impact on life on Earth and respect space

Planet workers really intend to achieve a breakthrough in the space industry, which they consider stuck in inefficient and unproductive old practices. They believe the current situation of space business calls for a more proactive attitude. From people like them who want to carve out a career in it, but also from everyone in the world. Co-founder and former CTO Chris Boshuizen states [4]:

"The space industry has been asleep for 30 years. I kind of feel like we're just waking up right now. I'd love to see more people starting companies in this space or similar spaces, just saying space entrepreneurship is back. I really want this company to not just show people what is changing about the world but show them how they can help".

This is what Planet's leaders call Global Sensing Revolution or Space 2.0 [2]. In a Sales Force conference [2], Will Marshall, asking for the aforementioned global collaboration, ends his speech posing an open question to his audience: "Imagine you had all these imagery data from the whole planet, then what would you do with them?" That says something quite meaningful to anybody trying to understand Planet's business model: it feels like the space start-up had little concern about having a clearly identified ultimate use of its products; probably Planet's leaders just believed that they could do something valuable in itself and decided to start doing it, with a firm conviction that applications would come alone. This is a smart idea, for it is not easy to foresee all the possibilities that could come before you even do that one thing that will change the game. It is interesting to see this approach of assuming risks, accepting possible failure and embracing challenge without guarantees reflected in its overall business approach, because it is the core of Planet's engineering philosophy.

It is undeniable that Planet workers take care of little details they consider meaningful, like the fact that they called their satellites Doves because "they're on a peaceful mission" [2]. That is a statement about their vision, but also a playful gesture when they call their constellations "Flocks".

Tech writer Kevin Roose, who interviewed Planet's representatives at their headquarters in San Francisco, wrote: "If you haven't heard of them, it's because they've been avoiding most interviews with the media until they're further along in the development process.". That is very true. When you perform a thorough search on Planet, you notice how, despite being founded in 2010 and successfully launching their first Doves in 2013, a good amount of publications arises in 2014, the year Will Marshall gave a TED talk [13]. While Planet is setting an example of uncertainty tolerance, it really feels like it has quite a lot of things under control.

A.3 Ownership and Employees

Two of the three co-founders remain today in the company: Will Marshall and Robbie Schingler. Will Marshall is CEO (Chief Executive Officer), leading the overall company strategy and direction. Robbie Schingler, who spent 9 years at NASA, is now Planet's Chief Strategy Officer. In November 2015 the third co-founder, Chris Boshuizen, who at that time was responsible for satellite production and the leadership of the engineering team as CTO (Chief Technology Officer), announced via Twitter he was leaving the company.

Along with Schingler and Marshall, there are seven more people in management positions in Planet Labs these days providing their lengthy experiences. Among them, Tom Barton is responsible for the company's business operations and Ryan Johnson the President, whereas Karthik Govindhasamy leads the engineering section and David Oppenheimer oversaw the financial aspects. Diagram in Figure has been specially designed for this case to show all nine people leading the company.

Figure A.1: Planet's Leadership team. Extracted from [14]

A.3.1 **Work Environment**

Some journalists who have visited Planet's headquarters in San Francisco have reported its creative, non-conventional environment: a drum set tucked in a corner, coders sitting on yoga balls and even a nap room with Star Wars sheets on the beds. But however fun it may look from the outside and probably is, space is a very competitive and technically demanding business field, and that surely is translated into the frantic rhythm of work at Planet.

In the employees' reviews of the company [15], no one conceals the fact that it is indeed a challenging job with long work days and always plenty of things to be done. Such an innovative approach does not help keep priorities clear nor maintain plans; it requires extra flexibility from everyone. But disrupting the space industry sure is exciting and having a humanity-centred mission is motivating.

A.4 Partnerships

The organization has established three types of partners which are correctly and presented with details in its website. Planet divides its partners between:

- **Solution Partners**, developing and selling solutions, from Planet's data. This partnership includes:
    - Application developers
    - Ecosystem developers
    - System integrators
- **Sales Partners**, selling Planet's data.
    - Representatives
    - Resellers
    - Distributors
- **Platinum Partners**, combining the creation and selling custom solution with the ability to sell Planet's products and offerings. These also have significant financial commitments that align to increased support and enablement.

Apart from this, the network of partners might be divided into the motivations which bring Planet to collaborate with this partner companies; the motivations are:

- Optimization and economy of scale.
- Reduction of risk and uncertainty.
- Acquisition of resources and activities.

Therefore, Planet establishes strategic alliances, coopetition relationships, buyer-supplier relationships and joint ventures with its partners.

By the end of 2019, the most important partnerships that Planet had established are presented in Table A.1.

Table A.1: Main Partnerships by 2019.

Company	Sector	Type of Partnership	Motivation of Partnership
Upstream PBC, Inc.	Intelligence	Solution Partner Strategic Alliance	Reduction of Risk
Farm Logs	Agriculture Analytics	Solution Partner Strategic Alliance	Reduction of Risk
Farmers Edge	Agriculture Analytics	Solution Partner Strategic Alliance	Reduction of Risk
Beam IO	Intelligence	Solution Partner Strategic Alliance	Reduction of Risk
Live EO	Intelligence	Solution Partner Strategic Alliance	Reduction of Risk
Trimble	Software Development	Solution Partner Strategic Alliance	Reduction of Risk
FeatureX	Artificial Intelligence Development	Solution Partner Strategic Alliance	Reduction of Risk
GeoSpark Analytics	Data Analysis	Solution Partner Strategic Alliance	Reduction of Risk
Agrian Inc.	Agriculture Analysis	Solution Partner Strategic Alliance	Reduction of Risk
AGI	Intelligence, Software	Solution Partner	Reduction of Risk

		Strategic Alliance	
Bird.i LTD	Data Analysis	Solution Partner Strategic Alliance	Reduction of Risk
BAZEAN	Natural Resources Intelligence	Solution Partner Strategic Alliance	Reduction of Risk
Anglo Gold Ashanti	Data Analysis	Solution Partner Strategic Alliance	Reduction of Risk
Farm Drive	Agriculture Analysis	Solution Partner Strategic Alliance	Reduction of Risk
Sling Shot	Artificial Intelligence Signal Processing	Solution Partner Strategic Alliance	Reduction of Risk
AllSource Analytics	Data Analysis	Solution Partner Strategic Alliance	Reduction of Risk
PCI Geomatics	Desktop Software	Solution Partner Strategic Alliance	Reduction of Risk
Beth & Bessi Inc.	Agriculture Analysis	Solution Partner Strategic Alliance	Reduction of Risk
Crowd A.I.	Artificial Intelligence Data Analysis	Solution Partner Strategic Alliance	Reduction of Risk
Orbital Insight	Imagery Processing	Solution Partner Strategic Alliance	Reduction of Risk
Boundless	Data Analysis	Solution Partner Strategic Alliance	Reduction of Risk
Windward	Data Analysis	Solution Partner Strategic Alliance	Reduction of Risk
Azavea	Software Analysis	Solution Partner Strategic Alliance	Reduction of Risk
RMSI	Software Development	Solution Partner Strategic Alliance	Reduction of Risk
FarmShots	Agriculture Analysis	Solution Partner Strategic Alliance	Reduction of Risk
PIXIA	Data Access Solutions	Solution Partner Strategic Alliance	Reduction of Risk
Airbus	Space & Defense Technology	Coopetition	Optimization of Resources
ESA	Space Agency	Coopetition	Optimization of Resources
NASA	Space Agency	Coopetition	Optimization of Resources
Geoplex	Data Analysis Intelligence	Strategic Alliance	Reduction of Risk
Harris ENVI	Geospatial Analytics Software	Strategic Alliance	Reduction of Risk
SpaceX	Launchers	Joint Venture & Buyer-Supplier	Acquisition of Services & Reduction of Risk
Rocket Lab	Launchers	Buyer-Supplier	Acquisition of Services
Google	Data Storage & Data Engineering	Joint Venture	Reduction of Risk
ISS	Deployer	Buyer-Supplier	Acquisition of Services

A.5 EO Market Segment & Requirements

Planet focuses on the market segment of very-high temporal resolution (daily revisit time) with medium spatial resolution (3 to 5m). Its primary product offering is Earth imagery and imagery-derived data products. The company states that the key differentiators of its dataset are: one, complete coverage of the entire Earth's land area at a resolution not currently available, and two, daily revisit of this sampled land area [3].

Planet's satellites are not tasked with searching for images; their Mission 1 (as Planet puts it) is to scan the whole Earth every day. Customers can then search for the images they want using GPS coordinates.

A spatial resolution of 3–5 m and a daily revisit time, along with the global scanning mission, make possible for Planet's imagery to track everything from crop yields to the evolution of Syrian refugee camps. The company does remark, however, that its products can be especially helpful for climate change monitoring. Fighting deforestation has always been the founders' favourite application: "The use case that inspires me the most is deforestation", Marshall specified.

One of the objectives of the constant monitoring mission is to be able to report changes on the Earth mass land. A probably unforeseen application of this took place around the 2015 earthquake in Nepal. Planet Lab images, taken before and after the tragedy, revealed two remote towns no one was counting with. Aid workers could send in medical assistance and supplies. CEO Will Marshall considers this a success in his original mission to use space remote sensing to help people on Earth: "It was the first time our data actually helped people in the real world. Not just some sort of Silicon Valley bubble of hypothetical, you know", he said.

Another of Planet's ambitions has always been to democratise access to data. When an earthquake struck Ecuador and a wildfire erupted in Alberta, the start-up made their high- resolution imagery of those regions available under an open usage license.

Recently, Planet has also expanded the target of its value proposition to a wider number of customer segments, starting to be a provider of intelligence to entities such as the NGA or NASA, providing them with daily updated imagery from any spot of the Earth's surface.

In the future, and after the development of Mission 2 is accomplished, Planet is expecting to expand its customer segments to an even wider spectrum.

A.6 Applications (Payload)

Its data come in multiple spectral bands (blue, green, red and NIR, Near-Infrared) with a pixel size of 3–3.125 m. The GSD (Ground Sampling Distance) is 3 m (International Space Station – ISS orbit) and 3.7 m (Sun Synchronous Orbit – SSO), and the Image Capture Capacity (ICC) is 150M km^2/day [16].

- **Basic Scene product:** only radiometric and sensor corrections applied to the data; product intended for users with advanced image processing and geometric correction capabilities only.
- **Ortho Scene product:** radiometric and sensor corrections plus orthorectified product; image product suitable for analytic and visual applications.
- **Ortho Tile product:** radiometrically, sensor and geometrically corrected and aligned to a cartographic map projection.

Ortho Tiles, which are the most processed product, are Planet's core product lines [16]. They are created from multiple orthorectified scenes in a single strip that have been merged and later divided according to a defined grid. Figure 9 is an explanatory picture of this which helps get the idea. Each Ortho Tile represents a real surface 25 km by 25 km and is referenced to a fixed, standard image tile grid system. This is useful for many different applications requiring imagery with an accurate geolocation and cartographic projection [16].

This sort of products nowadays might be differentiated depending on the constellation they come from, as well. This implies different sorts of resolution if images come from SkySat satellites (*TerraBella* constellation, *RapidEye* satellites or *PlanetScope* satellites). Being the first satellites the ones which provide better resolution, and the last one, the ones which provide the worst.

Apart from this, *Planet* reached agreements with NASA and ESA in 2018 to make use of part of the *Landsat 8* and *Sentinel-2* captured imagery.

A.7 Production System

Planet is fully vertically integrated, it operates all aspects of its business except launch [3]. The company uses an agile aerospace approach for the design of its satellites, mission control and operations systems, as well as the development of its web-based platform for imagery processing and delivery [16]. Below, the pillars of its engineering philosophy are addressed.

A.7.1 Supply Chain

Planet designed and manufactured satellites do not contain a single component directly sourced from the space industry [3]. Instead, they use commercial, off-the-shelf (COTS) components. Planet found out that efforts made by the consumer electronics industry to reduce price and schedule had resulted in an extraordinary component catalogue available to everybody. The start-up is convinced that it is no longer required to develop a specialised ASIC (Application Specific Integrated Circuit) when nearly all electronic functionality is already available in catalogue parts [3].

For instance, Planet takes advantage of the tools developed to perform the heat transfer analysis on the latest Ford Diesel engine, the electronic design tools used for the PlayStation 4, or some of the electronic testing houses present in Northern California available to perform environmental tests for the consumer electronic industry [3].

Traditionally, the space industry has been proudly acting like a global R&D department, pushing the technology limits and enabling advanced technologies to be developed and then adapted to everyday usage. At some point though this seems to have been inverted. Today, it is the consumer electronics industry who is behind the massive miniaturisation of electronics and technology that is enabling Planet to produce remarkable capability in a 5-kg satellite.

A.7.2 Lessons Learned

Planet Labs reports investing significantly in the packaging and the miniaturisation of satellite capability [3]. Aiming to compress most of the capability of a traditional small satellite, its engineers accepted the challenge to create an ultra-high-density microsatellite. To do that, they drew lessons from laptop PC (Personal Computer), tablet and smartphone industries. Putting some inevitably large components (like reaction wheels) aside, a Dove looks like those state-of-the-art consumer devices: printed circuit boards (PCBs) with a lot of layers, outstanding high density of surface mounted (SMT) electronics components, and hardly any internal cabling.

Planet remarks a trend not only towards further miniaturisation but also towards higher levels of integration, inspired by the levels of hyper-integration or shared resources in the automotive and electronics industries. Knowing that an effective integration or sharing resources among single components in a spacecraft is key to increasing the system's functionality and density, Planet has adopted this no-boxes approach: power supplies and other resources are shared by all instruments, radios or consuming elements.

As Planet Labs puts it, "Small parts make tough systems!" [3]. This summarises an additional benefit of this ultra-dense architecture: fundamental modes become higher (outside the operating regime) and stiffness is increased. Likewise, smaller busses lead to smaller, less complex payloads, which in turn reduce the team sizes, materials, costs and development timelines [3].

Planet follows the software team management motto "release early, release often". This means small iterative steps and early customer engaging. And, in this case, is literally reflected in the start-up's continuous cadence of launches. One complete iteration of a Dove satellite takes 8 to 12 weeks from design to manufacturing [3]. Most importantly, this prevents obsolescence by continuously integrating the latest technology improvements. Chester Gillmore, Planet's director of manufacturing, explains, "We're building satellites with computers that are six months old. Lots of satellites have 10-year-old computers". Also, the iterative process is continuously improved: Gillmore estimated version no. 9 of Doves cost around 35 percent less than the no. 7 and was completed four times faster.

A.7.3 Agile Philosophy

The agile development methods applied by Planet Labs are enabling its unusually rapid design lifecycle. This is an approach to software development extended in Silicon Valley, but Planet Labs is applying it to its hardware development too. It is what they call "building hardware as if it were software"[3] . Among others, it includes:

- Learning as the primary goal and success metric
- Building over documenting ("well-written code is its own documentation")
- User-centred design with early customer collaboration
- Respond to change over planning, in order to avoid fixing items out of the critical path. This allows distributing risk throughout the system and among stakeholders.

A.7.4 Testing

In the design of its first constellation (Flock 1), Planet Labs avoided the laborious process of developing a comprehensive thermal model. Instead, the company "relied on engineering best practices" [3]. The idea seems bold but turns out very sensible. Instead of putting a lot of effort into building the best possible version of a spacecraft (which has always a long way to go), why not send just an MVP (Minimum Viable Product), wait to see how things go—while learning—and do it better the next time. After all, we cannot send humans to Mars using only a first iteration of calculations, but when launching a nanosatellite to VLEO one can dare to take some risks—and maybe should do it. In fact, "This in-situ information is clearly better than any on-the-ground simulation, and is a great use of build a little, test a little", Planet's CEO remarks [3]. Besides, this approach allows learning more lessons faster than it would be possible through analysis and ground testing.

A.7.5 **Production Risks**

Even if the satellites you build are the size of a loaf of bread, "It's a risky business going into space, which we've experienced. We've had 10 launches, two of which exploded. One was the Antares rocket and one was the SpaceX rocket. We had 26 satellites on one and six satellites on the other and yeah, that sent our satellites to smithereens", CEO Will Marshall admitted.

However, as Marshall points out, the start-up was smart enough to put just a limited amount of its satellites in each of those launches [2]. Planet fosters a culture of risk tolerance and failure acceptance. Embracing risk means managing risk, which is basically done by distributing it.

"Rather than building redundant systems into a single satellite, which requires a larger team and more materials, thus higher costs, we build redundancy into the overall constellation. This puts the cost burden on the production rather than R&D, which is proportionally less expensive".

The company allows for a part of its satellites to fail, and designs the constellation taking that into account. In my opinion this like the engine-out design rule in aeronautics: engineers design each aircraft as if one engine was to fail during takeoff. In Planet's case, this approach provides reduced development times and results in an overall risk reduction. And it has the additional benefit of allowing A/B testing. Putting different satellite variants across the constellation is a good practice to keep improving the technology used without risking the whole mission , and it enhances adaptability to change [3].

This capability to respond to market shifts helps Planet amortise its satellites over shorter lifetimes, which is the reason why it is economically feasible for the start-up to build its constellation in VLEO.

A.8 Operations

A.8.1 Constellation Characteristics

Satellites designed and built by Planet are called Doves. Planet refers to a group of Doves deployed simultaneously into a single orbit as a Flock. A Dove is a standardised 3U CubeSat (10 cm by 10 cm by 30 cm) weighing 5 kg. Its payload is an optical system and camera: a Bayer Masked CCD camera with 90-mm aperture and RGB+NIR imaging with a resolution of 3–5 metres per pixel [17]. Each of these shoebox-sized spacecrafts is equipped with GPS (Global Positioning System) and a star camera that allow to position the image on Earth. The Dove's position is controlled through a combination of reaction wheels and magnetorquers, and it also includes radio antennas and fold-out solar arrays [18] that can be appreciated in Figure A.2.

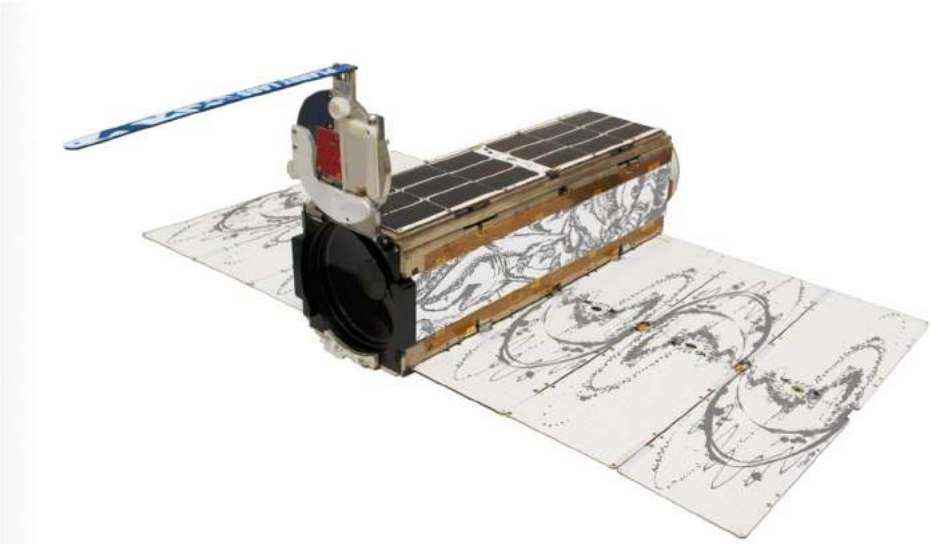

Figure A.2: *Dove picture. Extracted from [18].*

Doves are designed to be frequently updated and replaced, having each an expected operational lifetime of 1 to 3 years, depending on the type of orbit. In order to keep this continuous cadence of launches, Planet uses an agile aerospace approach to technology development. This (explained in the following section) means it uses rapid iterative design and frequent testing in space, which results in continually deploying improved spacecraft and payloads.

The complete PlanetScope (Planet's constellation built up of Doves) is designed as a constellation of approximately 120 satellites to be able to image the entire land surface of the Earth every day (i.e. a daily collection capacity of 150 million km2). This the updated constellation design reported in 2019, whereas the original design included up to 150 spacecraft.

Planet does not release great details about the constellation design. However, and as a hypothesis, these figures (previously 150, now 120 satellites) might indicate that the original design consisted of 5 orbital planes with 30 satellites each, whereas in the updated one the number of orbital planes would have been reduced to 4. Just like happened to Iridium, which had an initial design of 7 orbital planes with 11 satellites until the team of engineers realised one orbital plane could be cut down if the constellation was redesigned. Iridium's story is a fact.

Planet's satellites are deployed into two types of orbits: International Space Station (ISS) orbits are at a 52-degree inclination at approximately 420 km altitude, and Sun Synchronous Orbits (SSO) are at 98 degrees inclination or higher at approximately 475 km altitude. Here too there has been a change in the company's plans. Whereas in 2015 Planet stated that "Large constellations of satellites will be operated in both orbit types" [19].

In whatever orbit, Planet' satellites operate in a constant monitoring mode. Doves are not tasked; instead, they continuously capture imagery of the sunlit portion of the earth's surface [19]. This characteristic of the mission operations is highly relevant to Planet's business model, as it is explained in the section below related to Planet's products applications.

Additionally, and since the end of 2017, Planet counts with two additional constellations, the TerraBella and the BlackBridge ones.

The TerraBella constellation, acquired in the end of 2017, counts with 13 SkySat satellites, with a resolution of 0.8 m, in an orbit of approximately 500 km of altitude and with an image capture capacity of 32 million km2/day. Since the constellation was acquired, Planet has been working in the designing, updating and manufacturing tasks on this new sort of satellites, and applying its philosophy of replacing part of the most outdated satellites of the constellation with new evolved designs.

The BlackBridge constellation, composed by 5 RapidEye satellites, is in a 680 km sun-synchronous orbit. It counts with a resolution of 5 m and an image capture capacity of 6 million km2/day. This constellation, unlike the two previous one, does not represent any designing or manufacturing cost to the company, since no satellites from this constellation has ever been substituted by a new one, neither will be in case it stops being operative.

A.8.2 **Processing Data System (Ground Station)**

Planet Labs utilises a fully automated data pipeline that is designed to manage heavy data loads from a target fleet of up to 150 satellites operating in a constant monitoring mode. It uses two low-speed UHF systems for spacecraft operations and high-speed X-band system for downloading the imagery files.

The start-up has developed its own network of 31 ground stations, located in the US, UK, New Zealand, Germany and Australia. This network has been designed to ensure both efficient mission operations and successful downlink of imagery data. Each of those ground stations consists of an antenna and a Radio Frequency (RF) system, supported by a local computer server, connected to centralised services via secured VPN (Virtual Private Network) access. Downlinked imagery is transferred from the local ground station servers to the company's cloud infrastructure. From there, it is introduced into Planet's data processing and distribution pipeline to finally be delivered to customers [20]. Figure A.3 depicts this end-to-end data flow.

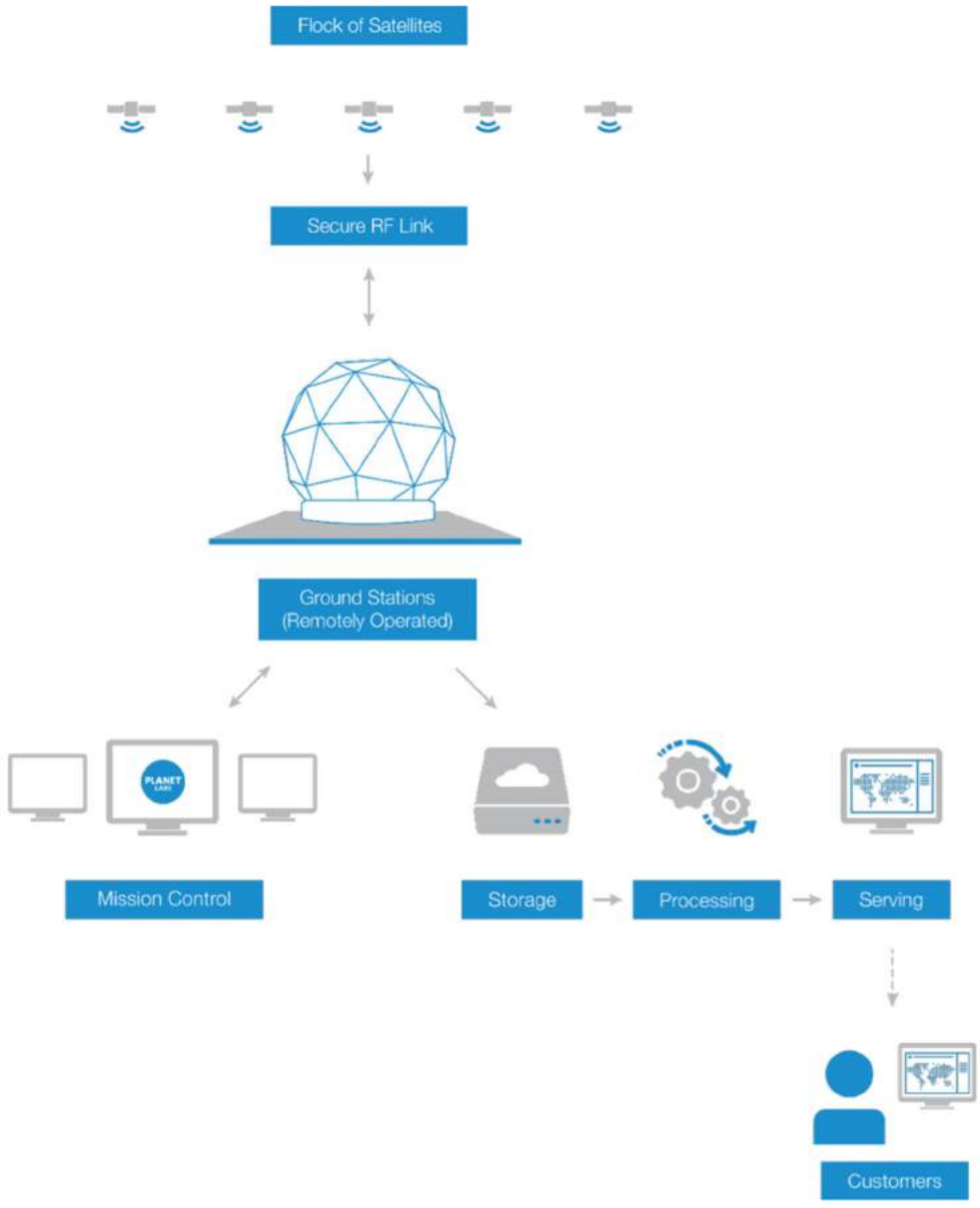

Figure A.3: Planet end-to-end data flow. Extracted from [20].

Such infrastructure will allow to collect and process 11 terabytes of imagery data every day [19]. All those image files will be available to customers within 24 hours from capture through the company's web product.

A good illustration of the high degree of automatization of Planet's operations is an incident that once took place. Two of their satellites got deployed overnight in a completely unscheduled deployment from the ISS. No one was on duty. The team went to work the following morning and just found a new pair of Doves on their screens. They had successfully commissioned themselves and started contacting the ground stations. Will Marshall says this is how Planet–accidentally—became the first company to commission a satellite (actually two) "without anyone in the loop" [2].

A.9 Online Platform

Planet has an online platform to offer to its client's access to the imagery produced by its devices. The Planet Platform is designed to be fast intuitive, and highly scalable. In Planet's website, it is described as a fully automated processing pipeline which provides with a powerful API and browser-based tools designed to make it easy to integrate the geospatial information and deliver analytic insights. [21]

A.9.1 Imagery Delivery

After acquiring Planet's services, customers gain access to two platforms through which products are delivered: The Application Processing Interface (API), and the Graphical User Interface (GUI).

The API is Integrated and built for scale. Planet's Platform is cloud-based, and it downloads, processes, and manages more than 5 terabytes every day. Also, its main objective is to offer to the customers the possibility to build tools, ingest data and run analytics to scale. It offers possibilities of listing, filtering and downloading the acquired data, images and intelligence results.

Another characteristic of the platform, is that the imagery is automatically corrected before being delivered to the customer, without costly post-processing or manual intervention, such as: [22]

- Orthorectification removes collection geometry, pointing error, and terrain variability distortions.
- Radiometric corrections correct for sensor artefacts and transformation to at-sensor radiance.
- Top- and bottom-of-atmosphere corrections reduce spectral inconsistency across time and location.

Therefore, the automation of the whole process makes possible the data to be downlinked, processed and published without any human intervention and the imagery is offered and available to be downloaded within 24 hours of delivery.

The second delivery online tool, the GUI, allows users to view time-lapse mosaics, search for data, save search the acquired data, filter the data information, zoom and preview imagery, view imagery details and use draw and imagery compare tools. Another part of the GUI is an administration and account management tool, used to manage user accounts overview, organization and sub-organization overview.

Lastly, Planet also offers an open media channel and creative commons CC-BY SA 4.0, were anyone may obtain and see the images uploaded to this platform by the company, if usage is correctly referenced and used.

A.9.2 Value-Added Services (VAS)

This company offers the imagery ready to be analysed without any additional cost. However, although this service can be considered as a value-added service, it has been observed that Planets is working on a more integrative project that could be better defined as a Value-added service than the orthorectification and the other automatic corrections.

Planet is developing a more integrated platform called Platform for Analytics, which is currently in pilot. However, the company offers some information about it an even early access to the program for the most curious ones.

The actions taken to enforce this research in improving the platform, as well as to create products which are more intelligence related, are related with the fact that by the end of 2018 Planet announced the achievement of an agreement of collaboration with Boundless, a company which will potentially help Planet on creating a more intelligence-related product using the raw data imagery as a starting point.

Platform for Analytics is defined in Planet's web as the solution to unify the imagery from the catalogue together with the analytic capabilities, all in a single API. The API allows to tap directly into the pipeline to define data processes and customize data delivery and management. More technical details are

specified in Planet's website that says API-first allows to programmatically search and download from their more than 6 petabyte catalogues with Planet's API, built on accepted REST, JSON, and HTTP standards. The API allows the customer to:

- Ingest only the imagery and associated GeoJSON metadata needed.
- Build atop Planet's API and easily integrate imagery into the tools and workflows.
- Set up custom notifications and get alerts when new imagery appears in the catalogue.

A.10 Financial Status and Risks

A.10.1 **Financial Status**

According to venture capital research firm Pitchbook Inc., Planet was valued at about $1.1 billion after its last round of fundraising (in April 2015). Since then, the San Francisco–based start-up has acquired BlackBridge (2015) and Terra Bella (2017), having the later been purchased by Google for $500 million the previous year [11].

Planet has been completely funded by venture capitalists in a series of funding rounds between 2013 and 2015. Altogether, it has raised $183.1 M. Table A.2 shows the amount raised in each round.

Table A.2: Planet founding rounds details.

Funding Rounds				
Date	Round	Amount ($)	Lead Investor	Number of Investors
Jun. 2013	Series A	13.1 M	-	7
Dec. 2013	Series B	52 M	Yuri Milner	13
Jan. 2015	Debt Financing	25 M	Western Technology Investment	1
Jan. 2105	Series C	70 M	Data Collective	17
Apr. 2015	Series C	23 M	IFC Venture Capital Group	5
Feb. 2019	Series D	168 M	-	35

Through these rounds, Planet has been funded from 58 different investors. They are some of the same investors who backed popular Silicon Valley companies like Facebook, Twitter and Tesla.

A.10.2 **Economical Risks**

Since launch costs basically depend on spacecraft weight and orbit altitude, these are also lower than usual. Doves are so light that the 28 of them in Flock 1 weighed less than 60 kg on a launcher. This means not only incomparably fewer kilogrammes than those in a 2-tonne Landsat, but also an adaptability that allows them to be contracted as secondary payloads, instead of requiring a more expensive dedicated launch. Likewise, Flocks are orbiting around 400 km above the Earth's surface, in contrast to the 700-kilometre altitude of Landsat satellites.

Appendix B: Case Study - DigitalGlobe

This appendix will present the Case Study of DigitalGlobe. DigitalGlobe is one of the leaders in the private sector of Earth Observation; it develops tasks related to image capture, satellite development and geospatial intelligence development This chapter is divided into History and Overview of the company (section B.1), Business Statement and Philosophy (section B.2), Ownership and Employees (section B.3), Partnerships (section B.4), EO Market Segment Requirements (section B.5), Applications and Payload (section B.6), Production System (section B.7), Operations (section B.8), Online Platform (section B.9) and Financial Status and Risks (section B.10).

B.1 History and Company Overview

Back in the 1990s, the only satellite images that users could get hold of were the ones from the space programs that governments sponsored. That poor-resolution commercial imagery was not even a primary mission goal, but only a secondary benefit. At that time, professionals like civil engineers planning channels to control floods or geologists exploring sites for mineral exploitation could not even dream of having access, right from their personal computers, to a digital library of high-resolution Earth images taken from space. This milestone would come with the launch of IKONOS-2 satellite in 1999, which became the world's first commercial satellite to obtain panchromatic (black-and-white) imagery with sub-meter (*0.8m*) resolution and multispectral images with 3.2m resolution [23]. Symbolically enough, this imagery was first released on the first day of the twenty-first century [24].

However, before that dream could come true and *DigitalGlobe* could be a part of it, there would be much more to come. Some attempts would end in failure; as an example, the *EarlyBird-1*, the company's first satellite, was launched in late 1997 but contact was lost four days later.

Some company merging would be required: while *DigitalGlobe* operated *IKONOS-2,* during its last two years of service life, the spacecraft was initially operated by *Space Imaging*, later called *GeoEye* and finally purchased by *DigitalGlobe*. But first, it was the law that needed to be changed.

It was January 1992 when the company was founded in California by Dr. Walter Scott as *WorldView Imaging Corporation*. That was nine months before the U.S. Congress passed the Land Remote Sensing Policy Act which would allow U.S. private companies to enter the space remote-sensing business. Entrepreneur Walter Scott was previously Program Leader of the Lawrence Livermore National Laboratory (LLNL) *Brilliant Pebbles* and *Brilliant Eyes* projects for the Strategic Defense Initiative. He was joined later that year by co-founder and initial CEO Doug Gerull, who was previously the executive responsible for the Geospatial and Mapping Sciences Division at Intergraph. Gerull would stay in WorldView until 2000 before the remote sensing firm adopted its current name and launched its first successful satellite, which would only come with the third attempt.

One year after its foundation, *WorldView Imaging Corporation* became the first company to receive a high-resolution commercial remote sensing license from the U.S. government. In 1995, *WorldView* merged with *Ball Aerospace*'s commercial remote sensing business, which brought communications and optics experience in satellites manufacturing. As a result of the merger, the enterprise became *EarthWatch Inc*. [25].

After its second satellite launched, *Quickbird-1* did not reach orbit due to a problem in the launcher in 2000. In September 2001 the company finally became *DigitalGlobe* [91]. One month into the renamed corporation's history, it launched its first successful satellite, *Quickbird-2*, built by *Ball Aerospace* and today usually referred to as simply *Quickbird*. In 2007 and aiming to increase its imagery distribution capabilities, *DigitalGlobe* purchased web-based satellite and aerial imagery provider *GlobeXplorer* [93]. In the following two years, the enterprise signed key agreements with customers like *Microsoft*, *Nokia* and *Google*. Those collaborations allowed DigitalGlobe to extend the reach of its products and services, enabling major mapping and LBS (Location-Based Service) applications featuring high-resolution satellite imagery [91].

While establishing those partnerships, the company also launched the first two satellites of its current constellation, *WorldView-1* (September 2007) and *Worldview-2* (October 2009), with 0.5-meter and

0.46-meter resolutions respectively and both weighing in excess of 2,000 kilogrammes [94]. That gained them the largest constellation collection capacity in the market [91]. Also, in that period, the business went public (2009) [91].

During the 2010s, *DigitalGlobe* has kept growing at a good pace. It has strengthened its position in the industry by merging with existing firms. Most notably, it merged with *GeoEye* in 2013 and, according to *DigitalGlobe*, it became a leader in satellite Earth imagery and geospatial analysis offering a wider range of products and services [91]. This was not only *DigitalGlobe*'s opinion, it was also a temporary concern of the antitrust section of the U.S. Justice Department, which investigated DigitalGlobe under monopoly suspicions [95].

The transaction, which combined the two main providers of commercial satellite imagery to the U.S. government, took place after the U.S. National Geospatial-Intelligence Agency (NGA) announced that EnhancedView, the 10-year contract of $7.3 billion that the two companies were sharing, would be significantly cut, but only affecting *GeoEye*'s part [96].

Now of merging, *DigitalGlobe* had possessed two satellites: *WorldView-1* and *WorldView-2*; the *GeoEye* acquisition added the *IKONOS* (previously referred to as *IKONOS-2*) and *GeoEye-1* spacecraft to double its fleet. Similarly, it also acquired *Spatial Energy* in 2014, gaining geospatial solutions from different sources for Energy companies, and *The Radiant Group* in 2016 [91]. Additionally, the Colorado-based company has continued to launch satellites, *WorldView-3* in 2014 and *WorldView-4* (originally built as *GeoEye-2*) in 2016, the latter doubling the corporation's capacity to collect the market's best resolution –30 cm— imagery [91].

In February 2016, *DigitalGlobe* announced the formation of a joint venture with *TAQNIA*, a Saudi Arabian technology development firm, in partnership with *KACST* (King Abdulaziz City for Science and Technology) to develop a constellation of 6 or more small imaging satellites with an expected resolution of 0.8 m [97]. *KACST* will be responsible for building and launching the satellites and will commercialise half the obtained imagery capacity of the Middle East. The other half and the whole capacity of the rest of the world will belong to *DigitalGlobe*. Such small satellites were scheduled for launch in 2018–2019 [98].

Today, *DigitalGlobe* owns and operates a fleet of 5 sharp-resolution satellites: *WorldView-1, GeoEye-1, WorldView-2, WordView-3* and *WorldView-4*, with spatial resolutions between 0.31 and 0.5 m. The technological sophistication of its fleet, together with its 25-year expertise, indisputably places the public company among the top positions of the global commercial satellite imaging industry.

The latest chapter in *DigitalGlobe'*s history opened in February 2017, when the company agreed to combine with *MDA* (MacDonald, Dettwiler and Associates Ltd.), a giant supplier of "space-based and airborne surveillance solutions, satellite ground stations, and associated geospatial information services" [99]. *DigitalGlobe* describes this as "an opportunity to create an integrated geospatial leader with end-to-end solutions" [100]. According to the agreement, the Canadian company will buy DigitalGlobe for US$2.4 billion in cash and stock and will assume DigitalGlobe's US$1.2 billion debt load [101]. *DigitalGlobe* will keep its name, brand and Colorado headquarters [99], and will become a subsidiary of *SSL* (Space Systems/Loral) *MDA Holdings*, the U.S. operating company of Canadian MDA [98].

MDA's acquisition of SSL (2012) and DigitalGlobe (2017) are part of the Canadian company's plans to boost its presence in the United States, with the goal of attracting more U.S. government business. As part of the effort, Howard Lance (a U.S. citizen) was named CEO of MDA in 2016.

B.2 Company Business Statement and Philosophy

DigitalGlobe is committed to helping the humanitarian community in large-scale crisis [114]. For that purpose, in January 2017 it created the Open Data Program for disaster response, aiming to assist response efforts by providing timely, critical information. Pre and post-event imagery would be released openly licensed for select natural disasters each year; besides, *Tomnod*, the company's crowdsourcing platform, will prioritise micro-tasking to expedite damage assessments [115]. This was the case of Hurricane Matthew, when imagery and the corresponding information extracted were used by organisations like the United Nations, the Red Cross and the Government of Haiti [114].

DigitalGlobe states that its purpose, vision and values extend into everything it does and guide the company: "From our strategy to our culture, as well as our commitment to helping our customers save lives, resources and time, we keep our Purpose, Vision, and Values top of mind" [127].

These is DigitalGlobe's business statement [127]. Its purpose statement is a registered trademark:

- **Purpose:** *Seeing a better World*. "By giving our customers the power to see the Earth clearly and in new ways, we enable them to make our world a better place."
- **Vision:** "By 2020, be the indispensable source of information about our changing planet."
- **Values:** "We are relentlessly committed to our customer and our purpose. Our values guide us as we help our customer save lives, resources, and time. We act with integrity, always. We treat people with respect in all dealings. We put mission and team before self. We inspire curiosity and harness innovation. Our results matter."

DigitalGlobe's brand is focused on quality. Moreover, it places great importance on not just doing things well, but on doing them better than anyone else. This feels like a remnant of the boldness that prompted Dr Walter Scott to find the company when the space remote-sensing business remained still unopened. Regardless of the evolution experienced by the space industry and the increased competitiveness, *DigitalGlobe*, the first private satellite-imagery company in the U.S., keeps its ambition intact.

This clearly shows in the company's Vision: "be the indispensable source of information"; but also in sentences like "*DigitalGlobe* is the World's leading provider of high-resolution Earth imagery, data and analysis" [105] and even "*DigitalGlobe*'s satellite constellation is the best in the world" [128].

This quality is translated into a relationship of confidence with clients, which the company highlights in speeches [126] and slogans: "Answers You Can Trust", in large lettering on its corporation website [129].

B.3 Ownership and Employees

The original founder, Dr Walter Scott, remains today in the company, although he is not CEO. He is executive vice president, CTO (Chief Technical Officer) and executive leader of platform and services in DigitalGlobe.

The complete Management Team comprising 17 positions is depicted in Figure 16, created according to the information made available at [102]. The most prominent position in the firm is held by Jeffrey R. Tarr, who is the president and CEO. Timothy M. Hascall is COO (Chief Operations Officer) and Gary Ferrera is CFO (Chief Financial Officer).

B.3.1 **Work Environment**

Today, *DigitalGlobe* has over 1300 employees scattered around the world [46]. Its headquarters are located in Westminster, Colorado but the company is extended across the United States from North California to Florida. It is also present in Canada (British Columbia and Ontario), South America (Chile and Brazil), Europe (Spain, UK, France, Italy and Denmark) and Asia (Russia, China, Japan, India, Thailand, Singapore and the United Arab Emirates). Finally, its offices in South Africa and Australia make the firm present on all the continents of the world.

On its website [46], *DigitalGlobe* highlights how many benefits its employees enjoy, from a professional development program to health insurance. In their reviews of the company [103], the workers particularly appreciate those, along with the efforts made by the firm to allow a good work-life balance despite the occasional heavy workload. Likewise, surveys completed by its employees gained *DigitalGlobe* the Top Workplaces prize by The Denver Post, which is shown at the top of *DigitalGlobe*'s corporative web page.

B.4 Partnerships

In order to develop its commercial activity, *DigitalGlobe* currently possesses a network of Key Partnerships, presented and explained in the following lines:

- **National Geospatial Intelligence Agency (NGA):** They present a government-industry partnership, through which, satellite imagery, captured by *DigitalGlobe* is helping in military operations and civilian healthcare issues amongst others. The partnership program is the *EnhancedView* program and is supposed to last at least until the end of 2020. [26]
- **Taqnia Space**: Both companies are working together so that the Scout constellation, composed by 6 small satellites, and manufactured by this Saudi Arabian company, might be launched as soon as possible. Scheduled launch date was supposed to be during 2019, but it has been delayed at least until 2020.
- **SAAB:** Back in 2015, *DigitalGlobe* and SAAB announced a joint venture, called the Vricon Joint Venture to create the globe in 3D. This model would be a photo-realistic 3D model and digital elevation model for enterprise and government geospatial markets, with unmatched coverage and delivery timelines. [27]
- **Timbr:** By the end of 2016 *DigitalGlobe* acquired Timbr, expecting to make it easier to explore the algorithms developed by their GBDX ecosystem and data partners, and accelerating the creation of new customer solutions. Timbr, a data science company, was supposed to provide new technologies and expertise to improve the usability and accessibility of the GBDX platform, allowing more customers to derive valuable insights about *DigitalGlobe's* satellite imagery. [28]
- **Radiant Spatial Energy:** Back in 2014, *DigitalGlobe* acquired Spatial Energy, a leading source for digital imagery and related services to the energy industry. [29]

B.5 EO Market Segment and Requirements

Its set of defence and intelligence customers, which is led by the *NGA* but includes other governments, represent a stable source of income. This is reflected in the *EnhancedView* contract with the *NGA*, which runs to August 2020 and represents *DigitalGlobe*'s core business. On the commercial side of the business, however, the company did not obtain the expected growth after investing in specialised products for specific commercial vertical markets [118]. Nevertheless, Tarr denied that the company was losing competitions to other providers and asserted that the problem was the markets had not developed [118]. An additional reason is a decision made by *DigitalGlobe* to not offer its 30-centimeter imagery to Google Maps, as a way to protect this market advantage. This is how Tarr explained this in another conference call with investors in July 2015 [119]:

"Based on our first few months in the market with our 30-centimeter imagery, we've decided not to undermine our value proposition to customers in other verticals by selling our best imagery at too low a price to a segment that would make this unique offer freely available on the Web. (…) This strategic decision is the single biggest driver in the modulation of our near-term revenue expectations".

On its website [107], DigitalGlobe points out 8 different industries where its satellite imagery, data and analytics may be applied. These are:

- Civil government
- Energy
- Global development
- Location-based services
- Mining
- U.S. government
- Defence and Intelligence
- Additional industries (like marine, agriculture and insurance companies)

While the U.S. government remains *DigitalGlobe*'s single-biggest customer, the company also counts with other buyers. Its client list includes:

- Some U.S. federal agencies like NASA [121] and the aforementioned U.S. Department of Defence's National Geospatial-Intelligence Agency (NGA) [122].
- Innovative tech companies like Facebook, UBER, Mapbox and Esri [123]. Moreover, Google Earth and Google Maps used to license most of their high-resolution satellite imagery from DigitalGlobe [124].
- Conservation organisations like the Amazon Conservation Team [125] or the Jane Goodall Institute [115].

B.6 Applications (Payload)

DigitalGlobe boasts about having the “sharpest resolution”, “largest collection capacity”, “unsurpassed haze penetration”, “broadest spectral diversity”, “best locational accuracy”, “largest historical library”, “unique cloud solutions” and “frequent revisit rate” [104].

The public satellite-imaging company does not make any information regarding temporal resolutions (allegedly its weak point) very easily available. Only somewhere [94] it is written that its satellite constellation has the “fastest 50 cm revisit times –intraday revisits.” However, it is a fact that the company offers real high-resolution images with 30 cm per pixel side [104] that collects at a rate of 3M km2 a day [105] or picks from a 16-year long archive.

DigitalGlobe focuses on a market segment that prioritises either spatial resolution or image quality over temporal resolution. Assuming a daily revisit time, *DigitalGlobe* would be offering a data with just the required temporal resolution by most businesses to monitor economic activity, at a spatial resolution well above the economic scale, according to what analysts in this field have reported [4].

The raw images obtained by *DigitalGlobe*’s satellite constellation are processed into different products to meet customer needs. According to a product catalogue of the company’s satellite imagery [106], this imagery is delivered in product levels designed for three different uses:

- Image manipulation and photogrammetric analysis by image processing systems
- Image viewing and feature analysis in geographic information systems
- Image viewing and locational reference by users in any application

All the satellite imagery products and their configurations are standardised for an easy ordering for the common market demands. Apart from these standardised products, *DigitalGlobe* is also offering customised services for customers requiring special configurations.

Selecting imagery for a product starts by defining an Area of Interest (AOI), which is the specific Earth area the customer is interested in. Given the AOI, the appropriate imagery is selected from *DigitalGlobe’s ImageLibrary* if possible, or a new collection request is submitted otherwise (dedicated operational mode known as “tasking” the constellation). Such AOI, in turn, gives the sum of square kilometres of the product, which will be used as the base unit of measure for product pricing [106].

Customers placing a new collection request can choose between default and advanced options regarding prioritisation level, cloud cover and delivery, in addition to the start and end date of imagery acquisition.

Whether the customer finds the desired imagery in *DigitalGlobe*’s archives or obtains it by a new collection request, it can be processed into multiple product options, as aforementioned. Product type and product configuration parameters are selected according to the intended use of the images. The product type has three value drivers: resolution (*Table B.1*), spectral bands (*Table B.1*) and product processing levels (*Table B.2*). All three selectable items impact pricing. On the other hand, the product configuration parameters are usually customer-driven preferences which do not affect final price. Such parameters include resampling kernel, dynamic range adjustment (*DRA*), bit depth, datum and projection, tiling and format.

Table B.1 shows the different resolutions and spectral bands available. Spatial resolutions are up to 0.3 m. Spectral bands available can be classified into 3 categories: panchromatic (1 band only, black and white), multispectral (4 or 8 multispectral bands) and pan-sharpened (an enhanced colour product with the visual information of the multispectral data and the spatial information of the pan data).

Table B.1: *DigitalGlobe* Product Options, extracted from [85].

Product Options		
	Pixel Resolution	Image Bands
Panchromatic	30 cm, 40 cm, 50 cm, as collected	Panchromatic
Multispectral (4-band)	1.2 m, 2 m, as collected	Blue, Green, Red, NIR1
Multispectral (8-band)	1.2 m, 2 m	Coastal, Blue, Green, Yellow, Red, Red Edge, NIR1, NIR2
Bundle (pan + 4-band)	30 cm, 40 cm, 50 cm, as collected	Panchromatic
Bundle (pan + 4-band)	1.2 m, 2 m, as collected	Blue, Green, Red, NIR1
Bundle (pan + 8-band)	30 cm, 50 cm	Panchromatic
Bundle (pan + 8-band)	1.2 m, 2 m	Coastal, Blue, Green, Yellow, Red, Red Edge, NIR1, NIR2
Natural Colour	30 cm, 40 cm, 50 cm, as collected	Blue, Green, Red
Colour Infrared	30 cm, 40 cm, 50 cm, as collected	Green, Red, NIR1
4-band Pan Sharpened	30 cm, 40 cm, 50 cm, as collected	Blue, Green, Red, NIR1

As Table B.2 shows, the products are offered in various processing levels depending on the corrections applied, from basic product (only offered by *DigitalGlobe*) to engineered product (with the highest geo-positional accuracy and best aesthetics).

Table B.2: *DigitalGlobe* Offered Product Options, extracted from [85].

Offered Products			
Product Name	Processing Level	Description	Benefits
System-Ready (Basic) System-Ready Stereo (Basic)	1B	*DigitalGlobe's* most basic product. Sensor corrected, un-projected (raw) product.	Ideal for 1) image manipulation and photogrammetric analysis by processing systems. Only *DigitalGlobe* offers this raw level of product with rigorous model for orthorectification.
View-Ready (Standard) OR2A View-Ready Stereo (Standard) OR2A	OR2A	Projected and resampled, projected to average base elevation.	Ideal for 1) Image manipulation and photogrammetric analysis by image processing systems, and 2) Image viewing and feature analysis in geographic information systems.
View-Ready (Standard) 2A	2A	Projected and resampled, coarse DEM applied.	Ideal for 2) Image viewing and feature analysis in geographic information systems, and 3) Image viewing by users in applications were location accuracy is NOT important.
Map-Ready (Ortho) 1:12,000	3D	High quality standardized orthorectified imagery. Not available using *Quickbird* Catalogue IDs.	Ideal for 3) Image viewing and locational reference by users in applications were location accuracy is important.
Map-Ready (Ortho) Engineered	3A-3X	Highest quality built to order orthorectified imagery.	Ideal for 3) Image viewing and locational reference by users requiring the highest degree of geo-positional accuracy or higher levels of aesthetics. Requires a custom feasibility analysis and additional price uplifts.

All these technical variations of the products are made available under a few commercial product lines, mentioned on *DigitalGlobe*'s website [107]. Table B.3 tries to classify and organise them considering the intended type of user (with varying levels of processing skills, and military). Relevant details given include additional descriptions provided by *DigitalGlobe*.

Table B.3: *DigitalGlobe* Product Details, extracted from [85].

Product Details		
Category	Product Form	Relevant Details
Imagery	Basic Imagery	For users with advanced processing capabilities.
	Standard Imagery	Georeferenced, ortho-ready imagery for processing, manipulation and data extraction. For remote sensing professionals.
Elevation Models	Stereo Imagery	For users with advanced processing abilities to build their own elevation model.
	Advanced Elevation Series	Full-service elevation data. For users needing off-the-shelf elevation models.
	Vricon 3D and Elevation	Surface models, terrain models, point clouds and 3D visualization available at scale, for network planning, line-of-sight analysis and situational awareness. For defence customers and extractive industries.
Datasets	Precision Aerial	To complement satellite imagery. For mapping applications that need consistency and completeness.
	SWIR	Short-wave infrared imagery. For applications in agriculture, forestry, mining and more.
	Human Landscape	Comprehensive human geography data in an analyst-ready format. For knowledgeable GIS professionals.
	Direct Access Program	Priority imagery for a dedicated purpose (tasking). For select defence and intelligence customers.

The company offers different access solutions for its products [107]:

- Basemap: user-friendly, for all users.
- FirstLook: for emergency service providers.
- GBDX Platform: *Digital Globe*'s Geospatial Big Data platform, for GIS developers.
- Maps API: for developers of location-enabled applications.
- Spatial on Demand: for energy industry experts.
- EnhancedView: for authorised U.S. government personnel.
- Image Connect: desktop extension

In addition to these products, *DigitalGlobe* also provides its customers with value-added solutions. The company points out [107] its expertise in the following fields:

- Analysis reports: predictive reports for business, market, environmental, political and military activities.
- Analytic services: location-based risk predictions.
- Crowdsourcing: leveraging thousands of imagery analysts.
- Human landscape: for expert GIS professionals.
- Marine services: for open-ocean sea fisheries.

B.7 Production System

Within the development of this section of the *DigitalGlobe* appendix, the processes that allow the company to develop its production tasks will be presented. This implies the Supply Chain activities, the partnerships which are necessary for the development of this tasks, the production process, the productive philosophy and the risks of production linked to the activities.

B.7.1 Supply Chain

DigitalGlobe has always outsourced the manufacture of its satellites. Its past and present satellites were built by Ball Aerospace (QuickBird, WorldView-1, WorldView-2 and WorldView-3), Lockheed Martin (IKONOS and WorldView-4) and General Dynamics (GeoEye-1) in Colorado, California and Arizona, respectively. Note, nevertheless, that all the satellites originally belonging to DigitalGlobe have indeed been manufactured by Ball Aerospace alone.

DigitalGlobe has teamed with a long list of industry leaders in various segments of the value chain, namely the production segment, the ground segment and the space segment. It has also outsourced internal business systems, e-commerce solutions, other software solutions and systems engineering [110]. Below is a roster of some of *DigitalGlobe WorldView* engineering and co-production partners, extracted from a press release [111]:

Table B.4: *DigitalGlobe*'s main Partners.

7.75	Sector	Type of Partnership	Motivation of Partnership
Aero-Metric	Data Analysis and Production	Co-production	Reduction of Risk
BAE Systems	Production Integrator	Co-production	Reduction of Risk
Ball Aerospace & Technologies Corp.	Spacecraft Developer and Integrator	Provider - Alliance	Reduction of Risk
Boeing Launch Services	Launching Services	Provider	Reduction of Risk
Boeing Space and Intelligence Systems	Engineering Services	Provider and Co-Production	Reduction of Risk
EarthData International	Data Analysis	Provider and Co-Production	Reduction of Risk
Environmental Systems Research Institute Inc.	Engineering Services	Co-Production	Reduction of Risk
Harris Corporation	Satellite Controller and Developer	Co-Production	Reduction of Risk
IBM	Computing Hardware	Co-Production	Reduction of Risk
InSequence	Systems Engineering Services	Co-Production	Reduction of Risk
IONIC	GIS Software	Co-Production	Reduction of Risk
MDA	Production Segment Developer	Co-Production - Alliance	Reduction of Risk
Jet Propulsion Lab	Orbit Determination Tools	Co-Production	Reduction of Risk
Observera	Calibration Services	Co-Production	Reduction of Risk
PRA	Engineering Services	Co-Production	Reduction of Risk
RT Logic	Satellite Interfaces and Control	Co-Production	Reduction of Risk
SAP	Collaborative Business Solutions	Co-Production	Reduction of Risk
ViaSat	Ground Antennas	Provider	Reduction of Risk

B.7.2 **Lessons Learned and Future Strategy with MDA in the front**

MDA's purchase of *DigitalGlobe* will, however, change this outsourced production system. As a result of the combination, the Canadian company will become an end-to-end space contractor, building satellites, developing communications and offering surveillance services [101].

MDA's Space System/Loral division, headquartered in Silicon Valley, will be responsible for building the future *WorldView-Legion* satellites in Palo Alto, California. According to Jeffrey R. Tarr, *DigitalGlobe* president and CEO, this will help *DigitalGlobe* fulfil its financial objective to reduce its capital intensity. "One of the important aspects of this combination is access to SSL's very advanced manufacturing capability and technology, and we believe that will contribute to reducing the capital intensity of the business", Tarr said [101].

Once best known for its high-power geostationary communications satellites, today *SSL* has expanded the capabilities of its manufacturing centre to building smaller, LEO imaging satellites. This happened when the Palo Alto–based company was contracted by *Terra Bella* (then *Skybox Imaging*) in 2014 to build 13 small Earth-imaging satellites of its *SkySat* series [112]. Those satellites were based on a *Skybox* design and weighed about 120 kilogrammes each. However, under the terms of the contract, *Terra Bella* (bought by *Planet Labs* in 2017) granted *SSL* "an exclusive license to the satellite design", according to *SSL* [112] or at least "certain intellectual property rights regarding its satellite design", like Anusuya Datta, Executive Editor of Geospatial World publication [113] and other authors [101] report.

To whatever extend, this allowed SSL to apply the know-how and technology to other small satellites. And, while *DigitalGlobe* has not wanted to reveal many details about its planned WorldView-Legion constellation, including the size of the satellites or the size of the constellation itself, some journalists advance [101] that SSL's new expertise in small satellite manufacturing finally be leveraged to build DigitalGlobe's next-generation satellite system.

B.7.3 **Agile Philosophy**

Back in 2004, *DigitalGlobe*, through an official press release, unveiled details about the company's next generation imaging satellite, the *WorldView.* This satellite, which at its time was to be the one with highest resolution, was supposed to provide the company with better agility, accuracy and collection capacity than any other known commercial system. Using the *WorldView, DigitalGlobe* would be able to expand its imagery product offerings to both commercial and government customers worldwide.

WorldView was supposed to work in combination with already orbiting *QuickBird,* acting as an operative constellation, constantly collecting high resolution imagery. With this launch, *DigitalGlobe* started adapting to the agile manifesto philosophy. The company started expanding the targeted customers, therefore, expanding the range of products which were being developed (though maintaining at its core the importance of the development of products intelligence-related). As well as constantly updating its software services.

B.8 Operations

This section will deal with the activities related to the operation of the company's owned satellites, as well as the activities related into transforming the raw imagery data into value products, and the commercialization of this products.

B.8.1 Constellation Characteristics

The fleet owned and operated by *DigitalGlobe* is comprised of 5 sophisticated satellites at operational altitudes roughly between 500 and 800 km [94]; all in sun-synchronous orbits. Aside from *GeoEye-1*, all the spacecraft weigh in excess of 2,000 kg and are the size of a van (5.7 x 2.5 m for *WorldView-3,* for instance).

Besides, the Longmont-based company owns the digital library of two retired satellites, *IKONOS* (1999–2015) and *QuickBird* (2001–2014), which acquired 408 and 636 million of square kilometres, respectively. That equals to 3 times and 4 times the world's land surface area [94].

For the purpose of clarification, satellites owned by *DigitalGlobe* from the very beginning are: *EarlyBird-1* (failed in 1997), *QuickBird-1* (failed in 2000), *QuickBird* (originally named *QuickBird-2*, retired), *WorldView-1, WorldView-2 and WorldView-3*. On the other hand, *IKONOS* and *GeoEye-1* previously belonged to *GeoEye*, like *WorldView-4*, which was built as *GeoEye-2*. All seven satellites have been launched from the Vandenberg Air Force Base, in the U.S. [108].

Despite *DigitalGlobe* operating them as a constellation, those spacecrafts do not share a common design. Figure 17 shows seven images that are reproduced with kind permission of European Space Imaging to show the overall design of the seven satellites owned by DigitalGlobe. Retired QuickBird (top row, left) and IKONOS (top row, centre) are also included to show the similarities between QuickBird and WorldView-1 (bottom row, far left), the first and second satellites originally owned by DigitalGlobe. Of the five operational ones, only WorldView-2 and WorldView-3 look alike, with the same layout of solar panels than WorldView-1 (a row of three panels at both sides of the satellite body); GeoEye-1 has all of its solar panels in a row, while the newest of the satellites has its solar panels displayed in star shape.

Figure B.8.1: *DigitalGlobe*'s satellites.

Table B.5 lists the specifications of each of the 5 satellites in the current constellation. Note how *GeoEye-1* is somewhat different from the rest; not only is it lighter, it also has the highest revisit time, it is the only one using reaction wheels, it has half the onboard storage and a slightly lower wideband data downlink rate. By contrast *WorldView-4*, despite being originally built as *GeoEye-2*, has very similar specifications to *WorldView-3*.

Table B.5: Specifications of the operational satellites in DigitalGlobe constellation, extracted from [85].

DigitalGlobe's Constellation Characteristics					
	WorldView-1	GeoEye-1	WorldView-2	WorldView-3	WorldView-4
Launch year	2007	2008	2009	2014	2016
Expected operational lifetime	13 years	10 years	13 years	12 years	7 years
Operational Altitude [km]	496	681	770	617	617
Spectral Characteristics	Pan	Pan 4 MS	Pan 8 MS	Pan 8 MS	Pan 4 MS
Panchromatic Resolution (nadir) [m]	0.50	0.41	0.46	0.31	0.31
Multispectral Resolution (nadir) [m]	N/A	1.64	1.85	1.24	1.24
Accuracy Specification (nadir) [m]	6.5 CE90	3 CE90	6.5 CE90	3.5 CE90	4 CE90
Average Revisit at 40º N latitude [days]	1.7	< 3	1.1	1.0	1.0
Weight Class [kg]	2,500	1,955	2,800	2,800	2,600
Attitude Control Actuators	Control Moment Device	Reaction Wheels	Control Moment Device	Control Moment Device	Control Moment Device
Onboard Storage [Gbits]	2,199	1,000	2,199	2,199	3,200
Wideband data downlink rate [Mbps]	800	740	800	800 or 1200	800

As previously pointed out, *DigitalGlobe* plans to expand its fleet by 2018–2019 with at least six small satellites built by a partnership with the government of Saudi Arabia, which is a Direct Access Partner. Such smaller-satellite system, called *Scout*, will have a resolution of 0.8 m and would be operated as a complementary constellation used to spot potential interesting targets and then call the higher-resolution primary constellation [109].

In addition, *WorldView-1 and WorldView-2* satellites are planned to be replaced by a next-generation satellite constellation named *WorldView-Legion*, to be launched in 2020 [101]. More details regarding the economic aspects of this plans can be found in the Financial Status section.

B.8.2 **Processing Data System (Ground Station)**

DigitalGlobe's Mission Operations Centre is supported by "highly automated systems" [114]. However, it is not fully automated, as it also counts with teams of four knowledgeable satellite operators working all day every day to fulfil thousands of taking requests per day [114].

The system collects more than 2,400 images every day (3 to 4 million square kilometres of Earth surface area), summing 70 terabytes per day to an image library of already 100 petabytes [114]. This is achieved through a global network of Remote Ground Terminals (RGTs) operated by the company. For security reasons, *DigitalGlobe* will not disclose the locations of those RGTs [115]

Since 2006, *MDA*, the global communications and information company, has partnered with *DigitalGlobe* to develop and deploy *WorldView* ground stations solutions into existing customer systems around the world [116]. In late 2015, the two companies signed a multi-million-dollar contract for MDA to provide a large number of international ground stations with upgrades in order to receive and process imagery also from *WorldView-4*, the company's latest satellite which would be launched the following year.

Such upgrades in *MDA*'s net of mobile and fixed ground stations would also give *DigitalGlobe*'s customers the possibility to access and process near real-time data from *RADARSAT-2* [116], a *SAR* (Synthetic Aperture Radar) owned and operated by *MDA*. DigitalGlobe also offers its customers access to Landsat imagery and high-resolution electro-optical and radar satellite imagery from other commercial providers [114], for an integrated source of satellite remote sensing capabilities.

Imagery received at an *RGT* is sent to the company's headquarters in Longmont, be it over the Internet or via a dedicated satellite link. There, it is decrypted and processed before it can be delivered to the customers. Delivery methods include media delivery (via DVD or external hard drive) [117], direct download and web platforms (like *Global EGD* and *My DigitalGlobe*); alternatively, it can be hosted in the cloud for analytic processing, using the company's Geospatial Big Data platform (GBDX) [114]. All in all, images get to the customers in between 12 minutes and 2 hours [114].

B.9 Online Platform

In order to commercialize the imagery and the intelligence extracted from it, *DigitalGlobe* needs to have a set of online tools to easily reach its customers. This tool will be introduced and presented in the following lines.

B.9.1 **Image Delivery**

DigitalGlobe offers different products for its Image Delivery. More specifically, the company has organised its offers into 23 different products, which are:

- Advanced elevation series.
- AW3D.
- Building footprints.
- Crowdsourcing.
- Direct Access Program
- Earth Watch
- Enhanced View
- FirstLook
- GBDX
- Human Landscape
- Imagery - Map ready
- Imagery - Short wave-infrared
- Imagery - Stereo
- Imagery - System ready
- Imagery - View-ready
- Maps API
- Mosaics
- New Collection Request
- Rapid Access Program
- SecureWatch
- Spatial on Demand
- Telco Geodata
- Vricon 3D

Additionally, it offers a series of programs, to be chosen by customer, listed and explained in the following lines:

- **Direct Access Program:** Direct Access enables defence, intelligence and commercial customers to integrate ground stations with the world's most advanced satellites. Local control and an encrypted downlink ensure a confidential end-to-end workflow within your communication cone. Customer acquires guaranteed access and data distribution rights to meet its needs. The partnership with MDA gives the customer access to the *DigitalGlobe* constellation as well as *RADARSAT-2*. The customers can directly control one of the *DigitalGlobe*'s satellites after reserving an access window.
    - Dedicated capacity and delivery speeds are guaranteed.
    - Task up to an hour prior to an imaging event and receive data in real time.
    - Manage the source lifecycle to maximize yield against geospatial requirements.

Some ways to use the Direct Access PRogram:

    - Situational monitoring for intelligence, surveillance and reconnaissance.
    - Transparency for evolving global insecurity.
    - Enhanced monitoring techniques for enforcing border controls.
- **Advanced Elevation Series**: Elevation and terrain information is foundational to mapping and understanding the surface of our planet. With global coverage and the ability to order custom-build models, *DigitalGlobe*'s Advanced Elevation Series provides the elevation data for fit the customer's needs, with options ranging from 2 m to 8 m in accuracy and resolution.
    - Customize the model:
        - Choose the resolution and accuracy which is needed.
        - Add an option like road flattening or hydro enforcement.
        - Bundle the model with the Advanced Ortho Series imagery.
    - Some ways to use Advanced Elevation Series:
        - Topographic mapping for improved construction of infrastructure planning.
        - Determine mineral categories and distribution at mining sites.
        - Transparency for evolving global insecurity.

B.10 Financial Status and Risks

B.10.1 Financial Status

In its 2017 first quarter results, *DigitalGlobe* reported having delivered “solid first quarter results with significant revenue growth across all of our major business units.” [130]. It stated it as continued to advance in their main strategic areas, enhancing its Imagery Leadership position (with the *Enhanced View SLA*, its highest revenue quarter in its DAP business and a 10% revenue growth in its Commercial imagery business), its Platform Leadership position (with important growth in GBDX, its geospatial big data analytics platform), and its Services Leadership (driven by the acquisition of The Radiant Group and also DigitalGlobe’s USG analytics services business).

It also reported being focused on “extending our technological lead while reducing our Capital Intensity” [130]. In this respect, the company reports starting to invest in WorldView-Legion, which, as explained in The Satellites and the Constellation section in page 59, is a next-generation satellite system to be launched in 2020 in order to replace the capacity of ageing WorldView-1 and WorldView-2. The entire spending program of WorldView-Legion (presumably including the spacecraft construction, launch, insurance and ground infrastructure) would cost no more than $600 million [130]. This is in accordance with the company’s intention to reduce capital intensity since the two old satellites to be replaced cost a combined $900 million, and WorldView-3 alone cost $600 million, according to Jeffrey R Tarr [118].

As for the company’s financial performance, it reports its revenue for Q1 2017 was $209.7 million, up 19.6% with respect to Q1 2016 (unless any other reference is given, all figures presented in this section are extracted from [130]. This overall revenue is split into the company’s main customer groups:

- U.S. government, with revenue for the quarter of $138.3 million, up 25.4% compared to the prior year period. Although the EnhancedView SLA remains flat, the U.S. government value-added services revenue increased from $22.2 million to $50.2 million, mainly due to The Radiant Group acquisition, but also for the growth in DigitalGlobe’s services business.
- Diversified Commercial, with revenue for the quarter of $71.4 million, up 9.7%. This comes primarily from sales of WorldView-4 imagery to some DAP customers and the company’s Global Basemap product suite. In fact, the DAP customer group experienced record revenue as a result of multiple crises in the Middle East, as noted in the section.
- Other Diversified Commercial, whose revenue was $35.3 million, up 10.7%, primarily from increased interest in the Global Basemap product suite, again, and the Platform business.

Appendix C: Case Study - UrtheCast

This appendix will present the Case Study of UrtheCast. UrtheCast is a satellite, imaging and geoanalytics developer company. It tracks long-term trends, it monitors shorter term changes, and it provides intelligence about guided, strategic actions to fulfil required missions. This chapter is divided into History and Overview of the company (section C.1), Business Statement and Philosophy (section C.2), Ownership and Employees (section C.3), Partnerships (section C.4), Market Segment (section C.5), Applications and Production System (section C.6), Operations and Production System (section C.7), Online Platform (section C.8) and Financial Status and Risks (section C.9).

C.1 History and Company Overview

As Wade Larson, the CEO and one of the founders of *UrtheCast*, explains in a TED talk [30] the beginnings of the company would be the following ones:

Early in 2009, Wade Larson, Scott Larson and George Tyc, founders of *UrtheCast*, were planning to put webcams onto the *International Space Station* (ISS) and stream images over the Internet. However, they met the aerospace Russian giant, *Rocket and Space Corporation Energia* (RSC Energia), which proposed to create a partnership to work on a payload for Earth Observation (EO) into the ISS and to install the cameras in a movable platform attached to the *Zvezda* service module from the space station. This change of plans leaded the executives of *UrtheCast* towards deciding on replacing one of the still cameras with a video camera[31].

In October 2011, *RSC Energia* and the Russian Space Agency approved the preliminary plans, but the intentions of *UrtheCast* were already published in its blog in June of the same year, explaining the intentions of the company to be like Larson said "*a live version of Google Earth combined with Youtube*". [32]. In the next posts in the *UrtheCast* blog, it was described the little advances in the project, showing the high degree in which and the Engineers and Designers of the company were working in order to develop the cameras that would be installed in the ISS.

Later in November 2011, *UrtheCast* announced the achievement of an agreement with the *Russian Federal Space Agency*, *Roscosmos*. Under the terms of this agreement, the *Russian Federal Space Agency* had committed to providing the pre-launch preparation, the space launch and delivery, the installation, and maintenance of the two *UrtheCast* cameras in the Russian module from the ISS. In an official communicate *UrtheCast* gave more details about the information obtained by the cameras, such as how the data would be downlinked via the Russian communications antennas, received on Earth at ground stations, and then transmitted to the *UrtheCast* operations centre where the video would be processed and made Internet ready. [33]. By the end of 2011, the company began developing an owned Application Programming Interface (API) that would allow the users to download the desired images of the areas of interest. In December 2011, *UrtheCast* announced the acquisition of the company GroundMap and expanded its business towards San Francisco, U.S. *GroundMap* is a company, founded in 2009, which developed activities as a social geo-tagging platform. It allowed for the tagging of all online media on an interactive map.

In January 2012, the company revealed details (for the first time) about the cameras that were being designed and produced [34]. This detail included information in areas such as the specific environment of the space and the external conditions that *Iris*, the high-resolution video camera, and Theia, the medium resolution camera, would have to stand. Both cameras were being developed by the team at the *UK's Rutherford Appleton Labs* (RAL) and would be ready for the fall of the same year.

In February 2012 *UrtheCast* announced a contract with *MacDonald, Dettwiler and Associates Ltd (MDA)*, a prominent provider of electronic solutions. Therefore, MDA would supply information solutions in support of the *UrtheCast*'s video of Earth from the ISS. [35]. Later in that year, in July 2012, UrtheCast and *Ustream Inc*, leader in live, interactive, and streaming video, announced an exclusive partnership to power up *UrtheCast*'s weekly live programming to *Ustream*'s wide audience. [36]

In November 2012, the company announced the launch of two cameras for the ISS, which was scheduled for 2013.

Continuing with the acquisition of partnership agreements, UrtheCast established bonds with *Discovery Science Channel*, with which it signed the first deal to provide live high-definition video of Earth for the Science Channel. *Discovery Science Channel* would also work on a special segment focusing on the *UrtheCast*'s technology itself. [37]

On 28th July 2013, along a payload of ISS supplies, *RSC Energia* launched the components that would support the installation of the *UrtheCast*'s cameras on the *ISS*. The launch was performed on Progress Supply Ship 52P from the Baikonur Cosmodrome in Kazakhstan. The procedure was successful, and these components would form the main structural base to which both cameras would be attached. [38]. After the reception of the hardware components, *UrtheCast* announced its finished installation in August 22, 2013. *Roscosmos* had successfully installed the Bi-axial Pointing Platform (BPP) on the Russian segment of the ISS, which is the structure to which the cameras would be attached. The BPP was attached to the Zvezda module on the Russian segment during the spacewalk #35. [39]

In September 2013, the company announced that the High-Resolution Camera had passed its first acceptance test. So, it could be sent from *Rutherford Appleton Laboratories* in the United Kingdom to S.P. Koroloev Rocket and Space Corportation (Energia) in Russia. The first test included electrical and functional test of the camera as well as full environmental testing such as thermal vacuum, vibration and electromagnetic compatibility. The second phase of test would take place in Russia after its arrival. [40] .

After the test were passed and the launch date was reached, *UrtheCast* announced the successful launching of the cameras was accomplished. The Progress 53P Cargo Ship carrying the *UrtheCast*'s cameras reached orbit following a successful launch from Kazakhstan Baikonur Cosmodrome. Travelling aboard a Soyuz rocket, they were scheduled to reach the ISS on November 29th. [41].

Once the cameras reached the ISS, the installation was performed on December 27th; however, Mission Controllers were unable to confirm that the cameras were receiving power from the ISS, therefore, as a safety precaution, the cameras were removed and re-stowed inside the ISS pending resolution problem. [42].

On January 7th, 2014 *UrtheCast* communicated the detection of the issue that delayed the initial installation and that such problem had been solved. The problem was found to be a cabling issue inside the ISS that could be detected, identified and corrected with the collaboration of the Moscow Mission Controllers, RSC Energia, and the cosmonauts. Therefore, the installation date was rescheduled to January the 27th. [43]. And as it was planned, on January 27th cosmonauts Oleg Kotov and Sergey Ryazansky performed the spacewalk EVA-37a to reinstall the two UrtheCast cameras into the Russian segment of the ISS and all the functionality and telemetry test were performed with satisfactory results. [44].

After the final installation of the cameras, the test and calibration process were performed in April 2014, when the first release of Earth Imagery from space was achieved. [45] In July 2014, Theia, which is the medium-resolution camera, was announced to be completing the commissioning phase and to be able to enter a new phase of obtaining commercial imaging, while *UrtheCast* continued refining the operational and processing systems. On the other hand, Iris, the high-resolution camera, was still being calibrated and the Bi-axial Pointing Platform was experiencing difficulties in achieving the pointing control precision needed to meet the quality specifications. [46].

In June 2015, *UrtheCast* finally released the World's first, full-colour HD videos of Earth filmed from the ISS at roughly one meter of resolution. The company decided to show the capacity of the high-resolution camera filming known cities such as are London, Boston and Barcelona. [47]. A few days later of the final HD video release, *UrtheCast* announced the intention to create a constellation, based on 16 satellites. However, two days later, *UrtheCast* made public the acquisition of the European

company *Deimos Imaging*, which operated two satellites, together with the Deimos global archive of Earth imagery. [48].

In July 2016, *UrtheCast* communicated the strategic partnership with *OmniEarth* to support the *UrtheDaily* constellation as well as to collaborate in the development of systems, to share the intellectual property or to share the marketing activities. [49]. Later on, in February 2017, *UrtheCast* and *GEOSYS* entered a long-term agreement as the agriculture anchor customer for the *UrtheDaily* constellation [50]. GEOSYS was one of the companies that collaborated with *UrtheCast* in order to establish the requirements to answer the need of the sector and to provide the design of the constellation.

The different important steps the company performed since its creation until nowadays are shown in the timeline in Figure C.1.1.

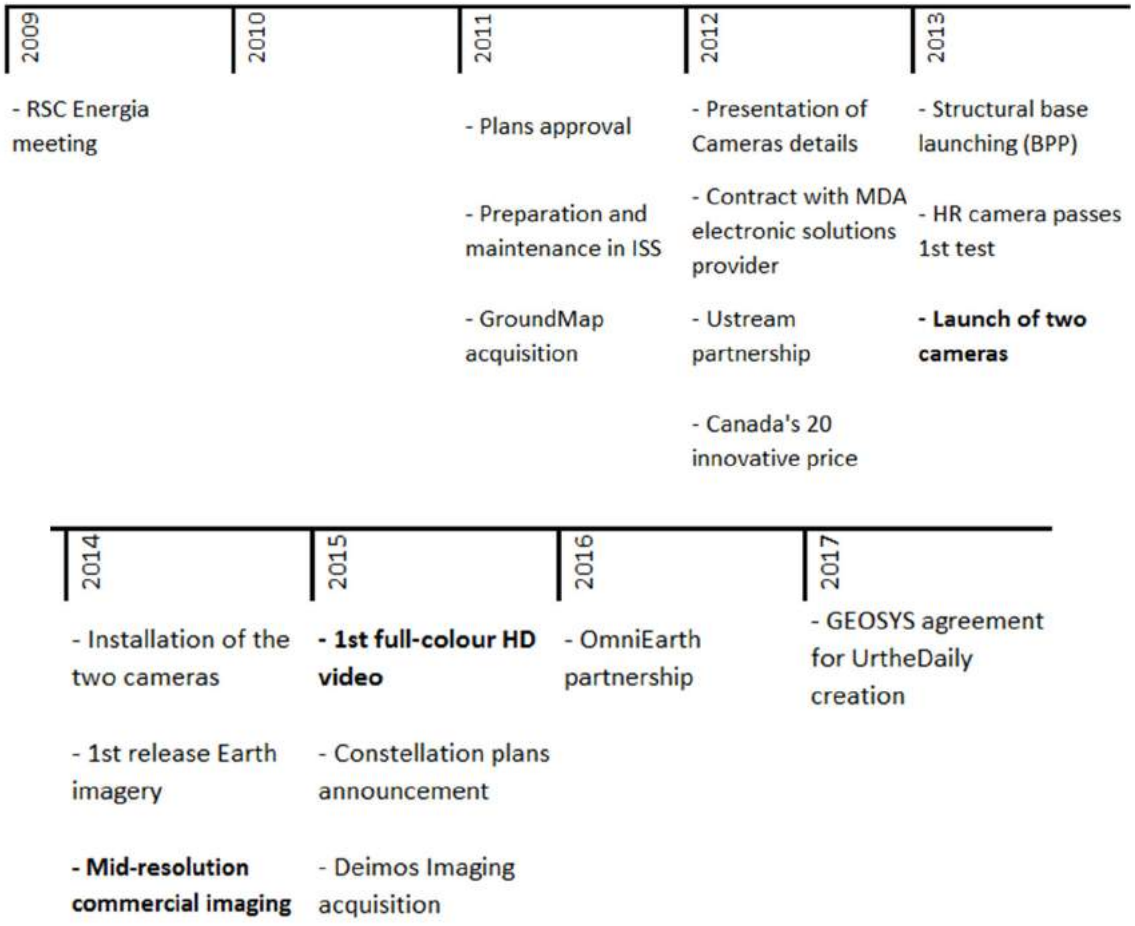

Figure C.1: Summary of UrtheCasts's evolution between its creation and 2017.

C.2 Company Business Statement and Philosophy

UrtheCast Corp. decided to define a document, the code of UrtheCast, where the Code of Business and Ethics would be detailed. Approved by the Board of Directors on July 10th of 2013, and amended on February 15th of 2016, in its introduction it states the that this document summarizes the standards of business conduct that must guide the organization's actions. This Code applies to all directors, officers, and employees of the *UrtheCast Corp*. and its subsidiaries. The Company has issued this Code to deter wrongdoing and to promote:

- Honest ethical conduct, including the ethical handling of actual or apparent conflicts of interest between personal and professional relationships.
- Avoidance of conflicts of interest with the interests of the Company, including disclosure to an appropriate person of any material transaction or relationship that reasonably could be expected to give rise to such a conflict.
- Prevention of the corruption of foreign public officials.
- Confidentiality corporate information.
- Protection and proper use of corporate assets and opportunities.
- Compliance with applicable governmental laws, rules and regulations.
- The prompt internal reporting of any violations of this Code to an appropriate person or person identified in the Code.
- Accountability for adherence to the Code.

The values of the company are [51]:

- Creativity, to use and design intuitive interfaces and adding value to the images obtained with the purpose of the Earth Observation.
- Collaboration, synergy between departments is crucial to develop a key product.
- Challenge, seek to get the solution to engineering problems and with the intention to go further each time.

As Cameron Chell, one of the co-founders of UrtheCast, explained in [52]: "*the main goal of the company is to provide high definition video with 1 meter of resolution of the Earth"*. Then, the main idea is to bring to the World the image of the Earth that the astronauts can see from the space in order to visualise that humankind is all one thing.

Additionally, *UrtheCast* also wants to democratise the access to life videos made from space and that anyone has access to it. The directors of the company have in mind that financing is a very important aspect and that that is the reason that makes them present their projects to fair trades, conventions and other acts because as Cameron Chell says "*If you can't finance that product, there's no point in building it, even if it seems there will be a great demand for it*".

C.3 Ownership and Employees

All the aspects related with the management team, board of directors and work environment have been investigated and explained in this chapter.

C.3.1 **Leadership**

Urthecast has assembled an international management team, divided into the Management and the Board of Directors. All the members have experience in leading and come to change the Earth Observation Industry. [53] Key members from the direction board are presented in the lines below:

- ***Wade Larson (President, CEO and Director)***, has over 20 years of space sector experience with the Canadian Space Agency. He has also extensive experience in space-related strategy formulation, business development, government relations, corporate development, and operations.
- ***Dr. George Tyc, PhD (Chief Technology Officer and co-founder),*** having worked on numerous space missions for over 25 years, Dr. Tyc is a recognized leader in the space in the space industry that has led multiple initiatives including the high-resolution optical EO satellite system and also developed the end-to-end system for the Earth imaging company RapidEye AG.
- ***Scott Larson (Co-founder),*** was the director until December 2015. He has achieved 11 years of experience in technology and corporate finance while developing advisory roles, helping small-to-medium companies in industrial, low tech, service, or manufacturing industries. He began his first start-up in 1995, he co-founded UrtheCast and more recently he is a co-founder and the CEO of Helios Wire, and Internet of Things start-up.
- ***Cameron Chell (Co-founder)***, is a new venture management consultant, specialized in Thinking BIG, Strategic planning and execution, Product development, Team Management, Measurement. In his LinkedIn profile, appears as the co-founder of nine more companies, and the CEO and Director of two.

C.3.2 **Work Environment**

Urthecast, following the latest tendencies in management has defined the Corporate Social Responsibilities (CSR) in the internal document “Code of Business Conduct and Ethics”, in which, apart from the safety and commitment to their employees, some other aspects such as basic obligations, conflicts of interest, confidentiality and competition are also taken into account.

Regarding safety, the organization is committed to making the work environment safe, secure and healthy for its employees and others. The individual value of the worker is analysed to perform any decision. They consider job performance, individual skills and talents, and other business-related areas, the most important factors to be considered. The organization also establishes that the Company’s policy prohibits discrimination in any aspect of employment based on race, colour, religion, sex, national origin, disability or age.

Apart from the documents that the company makes available to the public with its ethics and norms, a website to evaluate jobs in companies has been checked [54]. On this rating site, it can be seen the opinion of 4 anonymous employees which have been working in the company for around a year in engineering positions, and they all agree that the advantages of working in *UrtheCast* are the great work environment, the exciting goals, the knowledge and the people working there. Whereas the disadvantages are the location and salaries, that could be improved.

C.4 Partnerships

Within these lines, the main partnerships that *UrtheCast* has established, up to 2020 will be listed and presented.

1. **Roscosmos:** Under the terms of the agreement that both entities signed, the Russian Federal Space Agency committed to providing the pre-launch preparation, space launch and delivery, installation and maintenance of two *UrtheCast* cameras on the Russian module of the International Space Station. This agreement was a continuation of the exclusive agreement signed with RSC Energia, which at the time was acting as the prime contractor on the ISS related projects. [55]
2. **RSC Energia:** As part of the partnership agreement that both companies signed, RSC Energia launched, in July 2013, components that would support the installation of *UrtheCast's* cameras on the International Space Station. The launch of this these components was integral to the installation and operation of the cameras on fall of the same year. These components were developed, build and tested by RSC Energia. [56]
3. **Rutherford Appleton Labs:** Under the agreement that both corporations signed in the first stages of development on *UrtheCast,* it was stated that RAL would build the two high definition cameras that would be installed in the International Space Station. [57]
4. **MacDonald, Dettwiler and Associates, Ltd.:** In February 2012, both companies reached an agreement. As part of this agreement, MacDonald, Dettwiler and Associates Ltd. would supply information solutions in support to the *UrtheCast's* video from the International Space Station. Information solutions to be included in this agreement include space data handling hardware (data compression units), which would be integrated into the *UrtheCast's* two high-definition video cameras. [58]
5. **OmniEarth:** In July 2016, both companies announced the strategic partnership in support of the planned *UrtheDaily Constellation.* This partnership included collaborative system development, the sharing of intellectual property, and joint customer marketing activities. Back in 2016, OmniEarth was a large consumer of Earth imagery. This company specialized in image processing, data fusion, and predictive analytics, turning big data into actionable intelligence. One of the key market targets of *UrtheDaily,* which this partnership was to satisfy the rapidly growing demand for in-season precision agriculture. [59]
6. **GEOSYS:** In January 2019, *UrtheCast* closed the acquisition of Geosys Technology Holding LLC, for a price of US$20 million, payable in three instalments. As part of the first closing, *UrtheCast* entered into a 13-year agreement to provide Land O'Lakes with certain services which were at the time provided by Geosys. By unifying the companies, *UrtheCast* strengthened its position in fully integrated geoanalytics solutions for agriculture. [60]
7. **GroundMap:** In December 2011, *Urthecast* acquired GroundMap, a media geo-archiving and aggregator tool, which would allow for seamless social media aggregation into the *UrtheCast Platform.* As part of the acquisition, GroundMap would be merged into *UrtheCast* to lead the development of the *UrtheCast* web platform. [61]
8. **Ustream Inc.:** In July 2012, *UrtheCast* and Ustream Inc., the leader in live, interactive, streaming video, announced an exclusive partnership to power the *UrtheCast's* weekly live programming to Ustream's wide audience. The UrtheCastTV program provided insight to the domain of a space technology start-up. [62]

C.5 Market Segment

UrtheCast, with only 4 different devices has a wide range of products that can offer. These different devices, which are the two cameras installed on the ISS and the two-satellite operated by Deimos Imaging, offer different solution to different markets. According to *UrtheCast's* CEO, Wade Larson [63], "*the purchase of Deimos is a strategic springstone to the full constellation, because it starts to build the internal capabilities in terms of free-flyer management and operations to be ready for the future constellations to work on. Deimos-1 is a medium-resolution imagery satellite and it can be understood to not fit in the whole project, but it has the best coverage in the world for broad-area agricultural applications"*.

Therefore, in few words, UrtheCast owns a 22-meter wide area DEIMOS-1 satellite, 1-meter DEIMOS-2 satellite, a 5-meter multispectral sensor on the ISS and a 1-meter video camera on the ISS. These four sources of imagery offer UrtheCast to come to the market with four unique and different capabilities. Some of the usual customers of the services and imagery provided by UrtheCast, are companies which could fall into the categories and utilizations detailed below, which are: agriculture, emergences, environment, intelligence and mapping.

The applications that UrtheCast describes for its devices might be summarized into the following segments:

- Defence and Maritime, for government utilization.
- Infrastructure and Engineering.
- Natural Resources Monitoring; it includes the control of the water resources, agriculture applications and forests protection.
- Disaster Management.

C.5.1 **Agriculture**

Some examples of agriculture applications include drought assessment, crop management, crop insurance, grazing management, livestock stocking rate or grass availability. Deimos Imaging offers in its website value added agriculture services to customers. For this service, the satellite mostly used is the DEIMOS-1 as it has been specifically designed for this application. The 650 km swath provides wide areas to monitor and it has also been specifically designed to assure very-high-frequency revisit time.

C.5.2 **Emergency Services**

The wide swath together with the high resolution and high-frequency revisit times has made possible for Deimos Imaging, and therefore for UrtheCast, to offer good response to support actor dealing with Emergency Services, such as Civil Protection agencies responding to forest fires and flooding events. With the experience acquired during the years that Deimos Imaging has been working in the Copernicus Emergency Management Systems (EMS), they have established near real time delivery capability, being able to deliver a processed image in less than 30 minutes from its acquisition by the satellite. Those Deimos satellites provide 24/7 access to its satellite imagery services, particularly in emergencies or in response to requests for rescue operations.

C.5.3 **Environment**

An important part of the application of Deimos Imaging is to monitor the forests at stand level. The cloud-free imagery services have provided a capacity to focus on demanding areas of the world. The services that Deimos Imaging offers can be provided to public and private sector, and as an example, this company has worked to support the European Space Agency (ESA) in its *TropForest* project that works to estimate the degree of forest cover change and deforestation, or working with private companies to monitor forest plantations worldwide.

C.5.4 Intelligence

The imagery characteristics that Deimos' satellites provide allow the images taken to be used for surveillance over the globe. As they can be pointed to a targeted location, they can be used for specific operations or to gather information in response to emergency and crisis situations. DEIMOS-1 and DEIMOS-2 provide geospatial products that can have application in Defense sector including:

- ***Border surveillance***, by activity mapping, permeability analysis and monitoring of border areas.
- ***Maritime surveillance,*** application relevant with security and safety, as the monitoring of maritime pollution, detection of potential illegal, unreported and unregulated fishing activities and identification of probable polluting vessels.

C.5.5 Mapping

Mapping services include land use, mapping of irrigated areas, vineyard management and olive plantation. Climatic changes and the increment of global population have led to a need to implement management strategies to control and to have up-to-date data about the environment and how it is changing. DEIMOS-1 and DEIMOS-2 can provide detailed information for specific areas of interest about biodiversity, water bodies or urban areas. These images can also be integrated in a Geographic Information System (GIS) enabling quantification and mapping layers. Oil and Gas industry is an example of market that can have benefit from the satellite imagery since they are an extremely useful and cost-effective information source.

C.6 Applications and Production System

The camera systems which are operated by *UrtheCast* are part of an international project involving several nations, primarily Russia (through the Russian Space Agency), Canada and the United Kingdom. [64]

C.6.1 Camera design, development and production

The two high definition cameras were designed and developed in the United Kingdom by Rutherford Appleton Laboratory Space (RAL Space), which is a part of the Science and Technology Facilities Council/Rutherford Appleton Laboratory (STFC/RAL). These technical facilities provide the opportunity to test and verify the requirements that the product accomplishes and to check if it finally meets the initial requirements of the customer. RAL Space has experience in the space industry working for and with ESA and NASA.

RAL Space provides the following services:

- Definition and understanding test specifications.
- Assistance with the design and manufacture process of test fixtures.
- Adapting the facilities to meet exacting test requirements.
- Providing cost and schedule information.
- Ensuring a professional and reliable service.

Theia, the medium-resolution camera, is essentially a modified version of *RALCam3,* an existing and reliable space camera. The high-resolution camera, *Iris*, is defined as the most complex existing camera in RAL Space's website as it is explained that it would be placed on a steerable platform.

The RAL Space cameras interface with the data handling electronics, built by MDA in Canada, which pass the data through the ISS systems down to the ground where UrtheCast makes the images available for streaming to their customers and to the public. [65]

C.6.2 Data obtention and Ground Station Network

The acquired data is downlinked to a global network of antennas and backhauled to the *UrtheCast* cloud-based processing system and dissemination services. The resulting imagery and video are streamed in near-real time to the *UrtheCast* web platform or delivered to the customer as special-order products. [66]

Regarding the *DEIMOS-1* and *DEIMOS-2* satellites, *Deimos Imaging*, and therefore *UrtheCast*, owns two Mission Control Centres in Spain, placed in Boecillo and Puertollano, that provide platform operations and manage all communications with *DEIMOS-1* and *DEIMOS-2* satellites. These Mission Control Centres are operated 24 hours, the 7 days of the week and 365 days per year. Also, three secondary stations at high latitudes in Norway, Sweden and Canada, assure one contact every orbit with all satellites, allowing commanding and data download. Ground Segments are based on the gs4EO products, which depend of the company *Deimos Space;* for further information about these services, please, consult Appendix E section 9 (Online platform).

C.6.3 Launching and Installation in the ISS

Once the cameras have been designed, developed and tested, the next step is to launch them to the ISS and do the installation. First, the hardware and bigger components of the BPP (Bi-axial Pointing Platform), were launched by the company RSC Energia and later successfully installed by Roscosmos.

When the cameras were also ready, they were launched inside the Progress 53P Cargo Ship from Kazakhstan Baikonur Cosmodrome. [67]

C.7 Operations and Production System

UrtheCast was initially created to produce and place two cameras in the ISS to provide continuous Earth Observation images. However, in [63] it is related to the change of direction in the organization's strategy within a difference of weeks in June 2015. After the installation and the beginning of the ISS's cameras operation and the acquisition of the European Deimos Imaging company, *UrtheCast* owned four different sources of raw data which are detailed in the following sections of this appendix. In addition, the constellations that the company was planning to produce and develop for future operations and to provide service to a wider range of customers are presented. [68]

C.7.1 Current Operations

UrtheCast started developing the project to place two cameras, Iris and Theia to the ISS, and after it, the company acquired the company Deimos Imaging with its two satellites, which all together represent the active sources of Earth Observation Imagery that *UrtheCast* operates. Figure C.3 displays a representation of the Theia and Iris cameras in the Russian part of the ISS.

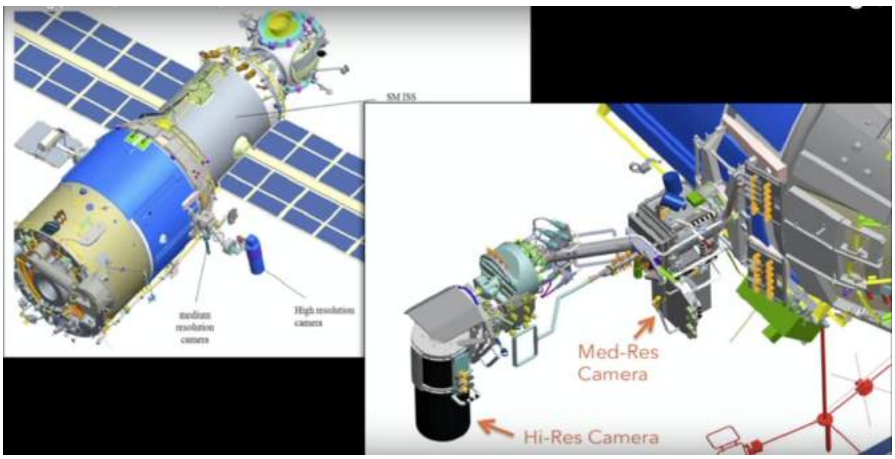

Figure C.3: Representation of the disposition of Theia and Iris cameras in the ISS Russian Module.

C.7.1.1 IRIS: Full Colour, UHD Video

Iris is the only UHD 1m full-colour video from space which provides unprecedented video of the planet. Iris is mounted on an agile pointing platform, the BPP, which allows the tracking of the targeted areas of interest and delivers videos that are approximately 60 seconds long. Iris uses a complementary metal-oxide-semiconductor (CMOS) detector to capture full colour UHD videos. Iris can also be controlled to continuously aim at a single point on the Earth's surface as the ISS passes overhead which allows the HRC (High resolution camera) to generate a video stream instead of single images.

The cameras are planned to capture the raw data and compress it using the JPEG2000 algorithm. The data from each camera is then stored on a computer and transmitted when the ISS is in sight of a receiver station on the ground. This process happens at least once per orbit, or every 90 minutes. From the ground stations, the data is uncompressed and uploaded to servers.

The orbit where the camera is placed is an ISS orbit, which is near circular, altitude in the range of 360-460 km, inclination of 51.6º, and 16 revolutions every day. Figure C.4 shows a real image of the Iris camera installed in the ISS and fully operative.

Figure C.4: Image of the Iris sensor placed in the pointing platform in the ISS. Extracted from: [69]

C.7.1.2 THEIA: Medium-Resolution Imagery

Theia is a 5m resolution camera, which provides a 4-band multispectral imagery, able to fit approximately 100 x 50 km in size. Theia imagery continuously flows into the company's cloud archive with no delay. Theia takes still images and to ensure it is pointing the right direction, and to cope with the vibrations of the ISS, the cameras are linked to star trackers for a better pointing accuracy. This star trackers provide information about the satellite, in this case camera, orientation in order to know the exact position in space.

Theia is pointed directly down to take continuous images of Earth. It is a push broom imager operating in four wavebands in the visible and near infrared, allowing colour images of the Earth's surface to be built up. The camera has a simple all-refractive optical design, well-matched to its resolution requirements without complexity, mass and expense of a mirror system.

Theia's lens system was designed using radiation stabilized glasses to avoid being vulnerable to the changes in transmission which can afflict standard optical glasses in the space radiation environment. The industry standard SpaceWire protocol is used for commanding and image download and a fully specified user interface allows programming of the camera to select parameters such as exposure time and image size. Theia contains an 8800-element linear Charge Coupled Device (CCD) plus all the electronics necessary to drive the detector and read out the image. Figure C.5 show's an image of Theia camera installed in the ISS while operating.

Figure C.5: Image of the Theia sensor placed in the pointing platform in the ISS.

Extracted from: [70]

C.7.1.3 DEIMOS-1: Wide swath imagery

DEIMOS-1 is described as an Earth Observation Satellite which captures 22m resolution imagery with a very wide swath of 650 km. It has been specifically designed to be able to cover large areas very frequently and is ideally suited for applications such as precision agriculture and forestry monitoring.

DEIMOS-1 was first designed to be added to the current first-generation Disaster Monitoring Constellation (DMC), coordinated by DMC International Imaging Ltd. (DMCii). The basic enhancement of the second-generation missions, also referred to as DMC-NG (Next Generation), was to provide wide-swath multispectral imagery at higher resolutions. The DMC satellites were built on a platform developed by SSTL under the British National Space Centre Micro Satellite Applications in Collaboration (BNSC MOSAIC) program. The spacecraft which are members of the DMC-NG are:

- DEIMOS-1: launched on July 29th, 2009.
- UK-DMC-2: launched on July 29th, 2009.
- NigeriaSat-2: launched on August 17th, 2011.
- NigeriaSat-X: launched on August 17th, 2011.

The DMC is a unique international collaboration of member nations and, through this contract, Spain joints the existing countries in the consortium (Algeria, China, Nigeria, Turkey, and the UK). Each member of the consortium owns and operates its own satellite whilst co-operating with the other members of the consortium. Therefore, DEIMOS-1 is a part of the DMC, but Deimos Imaging is the owner and operator of the DEIMOS-1 satellite and markets its images and value-added products worldwide.

DEIMOS-1 was focused on providing imaging services within the Iberian Peninsula region and Europe, but it is also used elsewhere around the globe. Alongside this, the missions will also support disaster monitoring as a part of the international charter for space and major disasters.

Enhancements in these new generation DMC spacecrafts include a modified payload design allowing a transition to a lower GSD whilst maintaining the 600 km swath. Improved power and data handling subsystems allow a greater imaging capacity so that swath lengths of up to 1,000 km can be captured. The higher imaging capacity is augmented by an X-band downlink operating at 40 Mbit/s.

The design lifetime is 5 years, and its envelope mass is approximately of 88 kg. The dimensions are 630 x 660 x 640 mm. The material employed for the spacecraft structure is aluminium-alloy and aluminium honeycomb panels and has been designed to be compatible with a wide range of launchers. The internal structure includes a stack of “micro-tray” modules traditionally used by SSTL in all its microsatellites. The stack of trays carries an optical platform, and between the stack and the panels, the battery, wheels and propulsion system are carried. The spacecraft also employs a fully passive thermal control system. Figure C.6 shows a digitized image of the satellite DEIMOS-1.

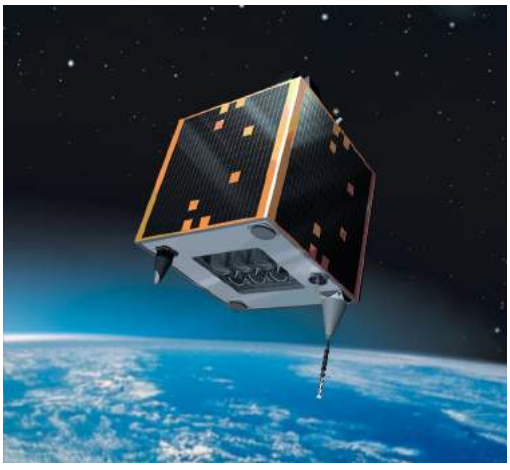

Figure C.6: *Image of the Deimos-1 satellite. Extracted from: [71]*

C.7.1.4 DEIMOS-2: High Resolution Imagery

DEIMOS-2 is a very high-resolution, agile and cost-effective satellite that provides 75 cm pan-sharpened imagery with a 12 km swath from its orbital altitude of 620 km. The agile spacecraft can be steered to accurately point the push broom-type optical payload, which can provide 1 m panchromatic and 4 m multispectral images. The multispectral capability includes 4 channels in the visible and near-infrared spectral range (red, green, blue and NIR). The off-nadir tilting capability of the spacecraft is intended to improve the revisit time performance and enhance the operational flexibility by significantly reducing the time interval to take images of the areas of interest. While the across-track tilt angle for nominal image acquisition is +-30º, the satellite can be configured to achieve +-45º off-nadir pointing capability, an extended Field of Regard (FOR) for data collection with short revisit times in emergency situations. Moreover, high-quality observations can be performed close to nadir (small FOR) to enable background mapping.

The contract between *Deimos Imaging Inc.* and *Satrec Initiative* for the design and development of the spacecraft was signed in November 2010. The satellite and its payload were being designed and developed by SI. And according to the agreements, the spacecraft would be integrated and tested in Spain in collaboration with SI, in the new Elecnor Deimos Satellite Systems at Boecillo, near Madrid. Deimos Satellite Systems is responsible for system engineering, procurement, testing, integration, launcher procurement, commissioning, in-flight acceptance, and operations of the system.

The project Preliminary Design Review (PDR) was in May 2011, and the Critical Design Review (CDR) was completed in June of 2012.

The spacecraft bus was designed to fulfil all mission requirements by incorporating 3-axis stabilized, accurate and agile attitude control for precise imaging operations. The satellite attitude is based on the following main nominal operations modes:

- Housekeeping sun-pointing mode in sunlight.
- Housekeeping nadir-pointing mode in eclipse.
- EO modes.
- Data download operation mode.
- Orbit maintenance and control operation mode.

The DEIMOS-2 minisatellite, has a weight of 310 kg and was launched on June 19th, 2014 on a Dnepr-1 vehicle of ISC Kosmotras. The launch site was the Yasny Cosmodrome in the Dombarovsky region of Russia. The nominal mission lifetime shall be 7 years, but there is a goal to last for 10 years. [72]. Figure C.7 shows a digitized image of the satellite DEIMOS-2.

Figure C.7: *Image of the Deimos-2 satellite. Extracted from: [73]*

C.7.2 Future Constellations

The next generation plan of *UrtheCast* is to provide an extended range of image to solve many different problems, by a customer-driven progression of sensors and infrastructure, based on three synergetic pillars which are shown in Figure C.8.

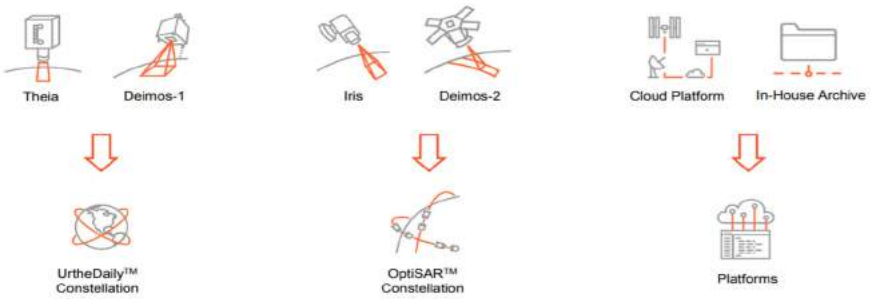

Figure C.8: Representation of UtheCast's plans of expansion.

According to Figure C.8, the three pillars that the company wants to base its operation in, are:

- **UrtheDaily constellation:** together with Theia and DEIMOS-1, to provide mid-resolution imagery and wide-swath information to supply customers whose needs have the specifications of quantity of data rather than the quality of the information.
- **OptiSAR constellation:** together with Iris and DEIMOS-2, to offer high-resolution imagery and the technology of Synthetic Aperture Radar to get information of non-visual data.
- **The online Platform** mixing the information of the Cloud platform with the received data from the different sensors, together with the archive imagery from previous operations, and offer a customized product for the client.

C.7.2.1 OptiSAR Constellation

Immediately after placing the cameras into the ISS, *UrtheCast* announced the plans to develop a 16-satellite constellation in partnership with Surrey Satellite Technology Ltd. (SSTL). As the interview by Space News to Wade Larson (the founder and CEO of UrtheCast) explains, eight of the satellites are planned to carry high-resolution cameras and the other eight synthetic aperture radar (SAR) payloads, making a fully integrated electro-optical and SAR constellation. [63]

The main distinctive characteristics of *UrtheCast new* constellation would be the concept of operations and the size of satellites.

- **Concept of operations**: The two types of satellites will be very close in a tandem pairs' formation, at an altitude of 450 km and about a minute apart. The constellation's formation of pairing is designed to allow for near-simultaneous acquisition of SAR and optical data. As described in the website, each pair is made to provide 1-meter resolution X-band and 5-meter resolution L-band imagery with a Ground Sampling Distance (GSD) of 0,5 m, and 0,5 m colour video at 30fps.
- **Satellites size:** They would not be using strictly smallsats. UrtheCast found out that there's a spot between the small satellites and the traditional ones between 600 and 1000 Kilograms, which presents an optimal relation between size and prestation.

The objective of the OptiSAR constellation is to revolutionize the world's ability to monitor our planet, everyday [74]. These 16 satellites make 8 tandem pairs that will be placed in 2 different orbital planes. OptiSAR is aimed at solving real-world problems and creating tools for World change to gain unprecedented and extremely valuable data regardless of obstacles like tree cover and weather

phenomena. Figure C.9 displays a digitized image of the constellation OptiSAR that UrtheCast is planning to develop.

Although UrtheCast announced in January 2017 [75] that it came into a binding agreement with a confidential government to be the customer for the sale and charred operation of the first two satellites in the OptiSAR constellation for USD 180 million, OptiSAR operations are not scheduled to start until 2021.

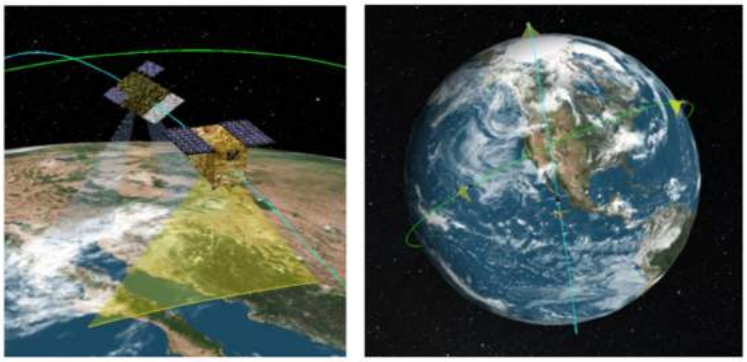

Figure C.9: Representation of the OptiSAR future constellation.

C.7.2.2 UrtheDaily

UrtheDaily, on the other hand, is presented in the website [76] as a planned global coverage constellation aiming to acquire high-quality, multispectral imagery at 5-m GSD, taken at the same time from the same altitude every day and to provide geolocation accuracy that will exceed the data quality of the RapidEye system. With its exceptional capabilities, it presents a disruptive and problem-solving technology that will transform the way we observe our planet.

The UrtheDaily constellation is planned to be composed of 8 satellites to produce consistent, reliable, daily delivery of 140M square kilometres of analytics-ready imagery. Those satellites, equally spaced, will be placed in a 600 km sun-synchronous orbit (SSO), 10:30 LTAN. Some more technical characteristics of the satellites and the constellation, such as the orbit, design life or size, are detailed in the Table C.1.

Table C.1: Main traits from the UrtheDaily Constellation.

UrtheDaily Constellation Details	
ASPECT	CHARACTERISTICS
Satellites	8 Equally Spaced Satellites
Orbit Parameters	600 km altitude SSO, 10:0 LTAN
Elevation Models	Stereo Imagery
Spacecraft	Based on SSTL-250 nus
Mass	340 kg
Size	1,1m x 1,1m x 0,8m
Designed Lifetime	10 years
Launching Vehicle	Falcon 9

Figure C.10 presents a modelization of the satellites position inside the constellation, and Figure C.11, displays an UrtheDaily satellite.

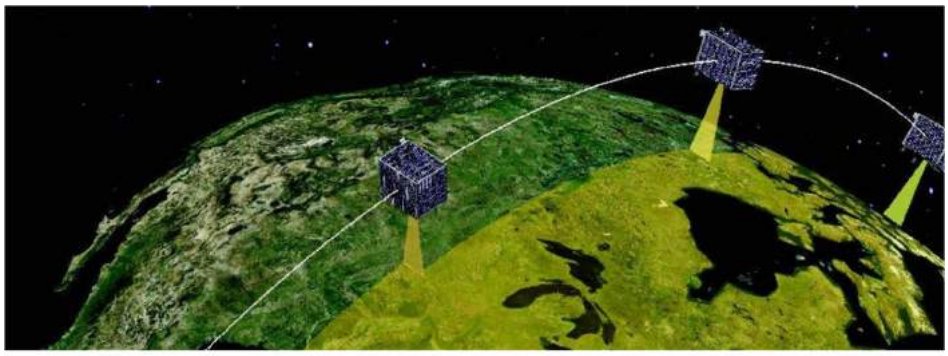

Figure C.10: Representation of the UrtheDaily future constellation.

Figure C.11: Representation of tan UrtheDaily satellite.

UrtheDaily was designed by *UrtheCast* by working with geoanalytics companies around the world to define and refine the data specifications required to ensure success for analytics partners. Some of the targeted specifically applications that will extract information from the imagery provided are:

- Scientific grade radiometric calibration
- High Signal to noise ratio (SNR) and bit depth
- High geolocation accuracy
- Narrow spectral bands selected to match Sentinel-2 bands and minimize effects due to atmospheric variations.

C.8 Online Platform

UrtheCast presents in a technical post the new Earth Application Programming Interfaces (API) to order GeoTIFF Imagery [77]. The new tool for the potential customer is introduced, and its functionalities and the procedure to work with it is described. These API allows the customer the direct contact with the imagery offered by the UrtheCast imagery sources and make easier the process of purchase. UrtheCast presents this platform as the key resource to connect customer with the Earth imagery provided by its collecting devices, being able to obtain images in GeoTIFF format which provides high resolution images.

Traditionally, the task of ordering historical satellite imagery involves phone calls, faxes and many other bureaucracies that make the process slow and outdated. Currently, big data allow to modify and improve this acquiring process of data. UrtheCast developed tools and services that simplify customers workflow. With the improvements, development and services of Internet, the development of APIs has been possible, and the company has taken an important role in the data treatment processes. APIs enable two pieces of software to work together and UrtheCast have designed its own API to fulfil the need of their customers who are interested in obtaining satellite imagery in GeoTIFF format.

As *UrtheCast* stated in [78], the new Ordering APIs are designed to address the data-centric and analysis-driven demands of EO customers by making it easy to extract data on-demand from their archive, from within existing software systems. Their entire archive data is now available for purchase and new data is made available throughout the day, every day.

Therefore, through its API, the purchase of the imagery needed can be easily completed. The company also takes into account that the speed of the transaction depends on the simplicity of the whole process so they have modelled it as a traditional e-commerce workflow where the different steps can be identified with the empty shopping cart, the products desired, the payment process, and the reception of the items bought.

It is worth to mention that when the order is being placed, the customer must specify the spectral bands desired to be included and to include only the area of interest.

UrtheCast defines its future objective regarding the APIs to be able to release additional value-added products that allow customers to more quickly derive business value from their data with increasing efficiency. The Ordering APIs are nowadays only available as an invite-only service, but they expect it will be available to general public in few months.

The company emphasizes the utilization of the APIs they have developed for data-driven decision-making models. They presume that thanks to UrtheCast, the customer can:

- Locate and save its area of interest.
- Predict and plan imaging opportunities using satellite trajectories and sensor footprints.
- Search, filter and refine all available data they provide.
- Subscribe to a feed of changes that have occurred in the area of interest.
- Visualize and render constantly refreshed Earth imagery.
- Extract GeoTIFF data in the bands that the customer needs about the area of interest.

UrtheCast additionally provides the access to the technical documentation about Earth data services in a comprehensive way, together with interactive tutorials with examples and visual tools to filter imagery before ingesting Map Tiles into the application. The companies interested in acquiring imagery from UrtheCast have two options: through a subscription to its API, or through the Customer Experience team. No matter the way chosen, additionally, UrtheCast offers an “advanced tasking” solution, which includes a trending topic engine which suggests places of interest based on current events.

Moreover, the orthorectification that the raw data captured needs, is offered by UrtheCast together with other processing image services to remove the headache from the map creation process. [79].

C.9 Financial Status and Risks

C.9.1 Financial Status

The company has open access to its updated accounts. Therefore, it can be analysed the last financial report published on 14th August 2017, with the results of the Second Quarter of the same year. Displayed in Figure C.12.

(in millions of Canadian dollars)	Q2 2017	Q2 2016	YTD 2017	YTD 2016
Revenue excluding non-cash revenue [1]	$ **11.9**	$ 15.9	$ **21.3**	$ 22.7
Revenue	**11.9**	21.0	**21.3**	33.1
Operating costs	**16.4**	22.4	**32.0**	46.4
Net loss	**(3.9)**	(0.3)	**(9.0)**	(11.4)
Adjusted EBITDA[1]	**0.9**	5.0	**(0.4)**	(1.0)

[1] *Non-IFRS earnings measure. See reconciliation to Revenue and Net Loss later in this press release*

Figure C.12: Summary of UrtheCast's financial results between 2016 and 2017. Extracted from: [80]

Figure C.12 is the summary of the financial results, which when compared to the same period of the same year to visualize easily the tendency of the company's liquidity. To analyse the chart, revenues have decreased by $4.0 million in the second quarter.

(in thousands of Canadian dollars)	Three Months Ended June 30,		Six Months Ended June 30,	
	2017	2016	**2017**	2016
Revenue	$ **11,854**	$ 20,973	$ **21,250**	$ 33,125
Other operating income	**61**	695	**111**	695
	11,915	21,668	**21,361**	33,820
Operating costs				
Direct costs, selling, general and administrative expenses	**10,894**	13,915	**21,403**	29,042
Research expenditures	**112**	1,493	**388**	3,229
Depreciation and amortization	**4,188**	6,392	**8,662**	12,956
Asset impairment	**309**	-	**309**	-
Share-based payments	**878**	565	**1,211**	1,123
	16,381	22,365	**31,973**	46,350
Operating loss	**(4,466)**	(697)	**(10,612)**	(12,530)
Net finance costs	**(436)**	(580)	**(878)**	(1,101)
Gain on derivative financial instruments	**681**	-	**923**	-
Foreign exchange loss	**(986)**	(210)	**(1,205)**	(402)
Loss before income taxes	**(5,207)**	(1,487)	**(11,772)**	(14,033)
Income tax recovery	**1,302**	1,210	**2,788**	2,656
Net loss	**(3,905)**	(277)	**(8,984)**	(11,377)
Other comprehensive income (loss)	**2,463**	(1,498)	**3,004**	(3,457)
Comprehensive loss	$ **(1,442)**	$ (1,775)	$ **(5,980)**	$ (14,834)
Net loss per share – basic and diluted	$ **(0.03)**	$ (0.00)	$ **(0.08)**	$ (0.11)

Figure C.13: Breakdown of UrtheCast's financial results between 2016 and 2017. Extracted from: [80]

NON-IFRS EARNINGS MEASURES

(in thousands of Canadian dollars)	Three Months Ended June 30,		Six Months Ended June 30,	
	2017	2016	**2017**	2016
REVENUE EXCLUDING NON-CASH REVENUE:				
Revenue per income statement	**$ 11,854**	$ 20,973	**$ 21,250**	$ 33,125
Non-cash revenue	**-**	(5,079)	**-**	(10,413)
REVENUE EXCLUDING NON-CASH REVENUE	**$ 11,854**	$ 15,894	**$ 21,250**	$ 22,712
ADJUSTED EBITDA:				
Net loss	**$ (3,905)**	(277)	**$ (8,984)**	$ (11,377)
Add back (subtract):				
Depreciation and amortization	**4,188**	6,392	**8,662**	12,956
Net finance costs	**436**	580	**878**	1,101
Income tax recovery	**(1,302)**	(1,210)	**(2,788)**	(2,656)
EBITDA	**(583)**	5,485	**(2,232)**	24
Non-cash revenue	**-**	(5,079)	**-**	(10,413)
Non-cash operating costs	**-**	3,811	**-**	7,877
Impairment of assets	**309**	-	**309**	-
Share-based payments expense	**878**	565	**1,211**	1,123
Gain on derivative financial instruments	**(681)**	-	**(923)**	-
Foreign exchange loss	**986**	210	**1,205**	402
ADJUSTED EBITDA	**$ 909**	$ 4,992	**$ (430)**	$ (987)

Figure C.14: Breakdown of UrtheCast's financial results between 2016 and 2017.

Extracted from: [80]

UrtheCast states in the analysis that, while EO imagery sales increased by $0.2 million compared to the previous year, engineering services revenue has been $4.2 million lower. This can be due to an adjustment in the second quarter of 2016 to record $8.0 million of engineering services revenue from a contract amendment, which included some services performed in the first quarter of 2016.

Operating costs of $16.4 million in the second quarter were $6.0 million lower than the prior year. When excluding the $5.1 million of depreciation and non-cash costs related to the ISS cameras, operating costs were $0.9 million lower than the same period last year, mainly due to lower salary and benefit expenses resulting from consolidation of certain software development activities and lower cloud storage costs.

The net loss of $3.9 million in the second quarter of 2017 increased by $3.6 million when compared to the prior year, primarily due to the lower engineering service revenues, which was also the main factor in the $4.1 million decrease in adjusted EBITDA compared to prior year.

C.9.2 **Risks**

UrtheCast company analysis performed by the company *Raymond James Ltd*. defines some of the risks identified during the complete research of the different aspects of *UrtheCast*, together with its industry and competitors. The risks identified for *UrtheCast's* activities are:

- **Political risk**: Although the ISS historically has not been impacted by political tensions, the cameras are located on the Russian modules of the ISS and this country operates and maintains the first-generation cameras. Sanctions related to political tension between Russia and any of the other nations funding the ISS could have an adverse effect on the company's assets and operations.
- **ISS operations**: The ISS has a programmed end of life in 2024, so all investments into cameras would be lost. However, common useful live of satellites are between 5-10 years, so the risk should be like other companies. Also, the plan of the deployment of the constellations UrtheDaily and OprtiSAR can replace the lost capacity of the ISS cameras.
- **Business disruption**: If some camera is damaged, it could take the camera offline until a spacewalk is commissioned or depending on the resources available in the ISS. On the other hand, being installed on the ISS that can provide maintenance and resources is an advantage that stand-alone satellites do not have.
- **New technologies**: Iris has a delay in its "first light" and commissioning due to engineering issues with the BPP on which the HRC is mounted. Delays in commissioning of current and future cameras could impact UrtheCast progress.
- **Space risk**: UrtheCast's cameras are placed on the ISS at 400 km above Earth and orbiting at 7 km/s. Obviously, there is an operational risk when dealing with environmental conditions in space. There is also the risk of damage from space debris which can delay or interrupt data capture.
- **Data distributor risk**: UrtheCast relies on foreign regional distributors and partners to market and distribute their data imagery. Failure by distributors and partners to market and sell the company's imagery and services could negatively affect potential revenues.

Appendix D: Case Study - Satellogic

This appendix will present the Case Study of Satellogic. Satellogic is the first vertically integrated geospatial analytics company, and they develop tasks related to satellite design and assembling, AI expertise or geospatial intelligence and solutions providement. This chapter is divided into History and Overview of the company (section D.1), Business Statement and Philosophy (section D.2), Ownership (section D.3), EO Market Segment and Product Lines (section D.4), Production System and Lean Manufacturing (section D.5), Operational Satellites in Orbit and Future Deliveries (section D.6), Online Platform (section D.7) and Financial Status (section D.8).

D.1 History and Company Overview

While Emiliano Kargieman, founder of *Satellogic*, was in a summer course in NASA's California base, in 2010 he was surprised that the technology used for the satellite's development was almost the exact same one which existed in the Apollo mission's era. Due to this fact, he started thinking about how to impulse the space technology as well as it happened with mobile phones or personal computers, and he got the idea of developing a new kind of small satellites, which would be 20 cm length and 10 cm width, with the main objective to democratize the access to space related information and the intelligence it can provide. To do so, he returned to his motherland, Argentine, to start developing this first project idea.

After the creation of Satellogic, the argentine company dedicated its main activities to applied investigation, which granted them a NASA qualification. This relation helped him with the process of obtaining the knowledge for the development of *Satellogic'*s first satellite, called Capitan Beto, which was launched in a Chinese shuttle in April 2013. [81]

In November 2013, after finishing their second satellite production, *Satellogic* published the technical code and the details for the mechanical and electrical engineering of all the components of the newly developed satellite, in order to democratize the space market which was one of the main objectives the company was aiming to. [82] Despite promising to keep on explaining their developments and achievements, after 2013 no further technical communications were released. However, *Satellogic* kept on working developing their business model and the satellites that would conform the *Aleph-1 constellation*. Under this purpose, in April 2014 *Satellogic*'s training phase ended, with the launch and operation of the third prototype.

Later, in May the 30th of 2016, as the first operational and commercial satellites of *Satellogic*, *Fresco and Batata*, were launched. Its success lead to the Argentinian government to meet Emiliano Kargieman to congratulate him for the operation and for its company success. In September of the same year, Kargieman was chosen by the Financial Times as one of the *Six men and women shaping how the World views Argentina.* [83]

In March 2017, NASA's EO-1 satellite was dismantled and Satellogic became the unique provider of hyperspectral imaging. [84]. At middle June of the same year, the company got 27 million dollars of investment funds, from a group of companies, the most known of them are Tencent, which is a Chinese technology specialized company, the Brazilian investment fund Pitanga, and CrunchFund, from the U.S. [85] The company stated that those funds were going to be invested in research and development, to have capital for the satellites production and to enhance the sales department of the company. [81]

Also, in the 15th of June 2017, *Satellogic* had another successful launch, this time the third operational satellite, called Milanesat, using a Chinese space shuttle, the same as the two previous commercial satellites. In November the same year, the newspaper Clarin released a stating that Satellogic had reached an agreement with Microsoft in order to use their cloud-based system, Azure. This agreement would provide space to storage the data captured, but above all, a platform where to analyse and process the information compiled by the satellites. This volume of data was expected to grow exponentially as the company would be launching more satellites into near space. The main aim of the joint venture was to collect the amount of inedit information of the Earth in order to reach

higher knowledge about our planet. As it was planned to analyse the data using Big Data and Machine Learning processes, it is expected to be key in the development of some industries such as agriculture, oil and gas control, or disaster monitoring, among others.

The joint venture with Microsoft did not mean big investments. In fact, Satellogic would have to pay for Microsoft's services. However, Satellogic would take advantage of Microsoft's sales to offer the services of the satellite information.

As it has been stated, one of the main objectives of the organization is to democratize the access to space information. Satellogic wants to achieve it by offering access to their images to the scientific community in order to provide the data for future investigations and allowing the development of improvements in science and humanitarian aspects. [86]

To continue with the constellation expansion, two more satellites, Ada and Maryam where launched in February 2018. The same month, the Spanish edition of Fortune magazine analysed the company Satellogic together with blockchain, not only for doing a revolution in the business world, but to be initiating the restructuring of the future.

In the same article, apart from analysing and explaining the successes and the plans of the organization they talk also about Emiliano Kargieman, who has the characteristics of the people who lead the new race to space: small and agile companies which are distributed and focused on objectives, supported by risk investments, and lead by young people who aims to change the world. [87]

In order to visualize the whole history of the company, the Figure D.1 shows a timeline with the information explained in the previous paragraphs.

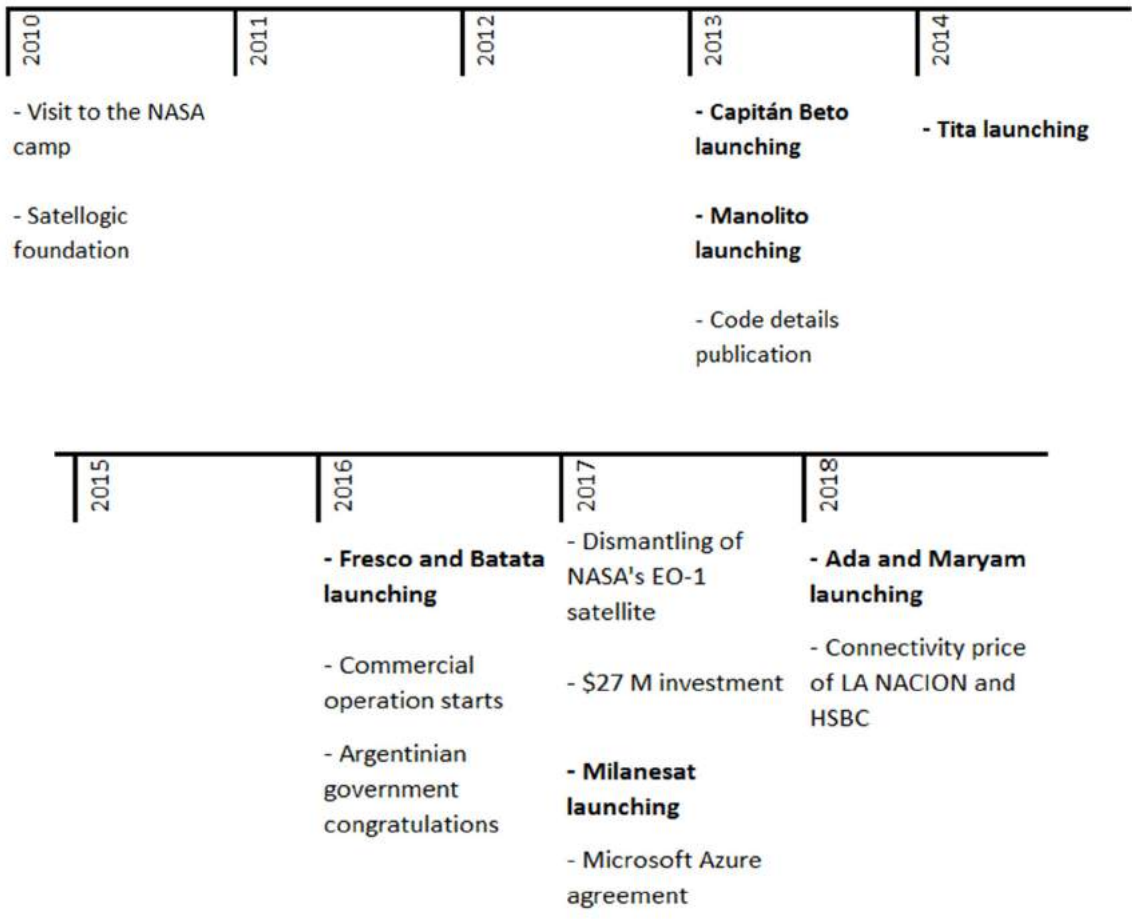

Figure D.1: Summary of Satellogic's activity up to 2018.

D.2 Company Business Statement and Philosophy

Satellogic defines itself through its value proposition, as it can be seen when analysing its brand defining phrase: *Enabling live geo-information analytics.* This part of the company's presentation continues with a more specific intention of providing high-frequency, high-resolution and affordable imagery as the key to the power of the decision-making process.

Additionally, the company keeps on presenting itself with the sentence: *Live insights from planet Earth*, which expresses the mission of the company to show the functionality and the processes of the Earth's life from itself. They claim that *their goal is to enable real-time understanding of our planet*; referring to the idea of the real-time monitoring of the events and to easy make smarter decisions based on updated global data. And as they interpret it: *By monitoring changes in real time on a planetary scale, we are transforming our relationship with the planet, helping us tackle the most pressing challenges, and creating a new layer worldwide awareness.*

In an interview with Infotechnology [88], Kargieman, *Satellogic's* founder and CEO, publicly stated that the company is not interested in earning large amounts of money, because it can lead to bad decisions, contrarily, the company is focused in offering the value it can provide by developing products and technology that could bring them to the leading of the industry, in which *Satellogic* works by demonstrating the benefits of hyperspectral imagery to potential customers. Specially the information that can be exported when high-resolution images and other data sets are combined. [89]

D.3 Company Ownership

D.3.1 Company Leadership

The ownership and management of *Satellogic,* lays down on the shoulders of the following people:

- ***Emiliano Kargieman*:** Founder and CEO of the company. He defines himself as a hacker. He started playing with technology when he was of very young age; he claims to have spent large amounts of time disassembling and reassembling the radios, TV and the first computer he owned. These activities gave him enough experience to be part of the group of hackers that composed the "*Dirección General Impositiva*", devoted to checking the cyber security of the organization. After a summer camp to a NASA investigation centre, he refocused all his attention on the aerospace industry. [90]
- ***Gerardo Richarte:*** Partner and Chief Technology Officer. With more than 15 years of experience in information technology, he co-founded the company *Core Security Inc*. with Emiliano Kargieman. When Kargieman had the business idea for *Satellogic*, he considered that Richarte had to be part of the leading team again, and from then on, he has been developing and operating the company's satellites. [91]
- ***Federico Jack:*** Vice-president of Operations. He is a business professional with financial analysis background. With more than 10 years of relevant financial work experience building and managing teams at fast-paced growth companies. He was director of Finance and Operations for five years in Auth0, and previously an Advisory board member in Nxtp labs.
- ***Bruno Sánchez-Andrade Nuño:*** Vice-president of Impact. He is doctor in Astrophysics by the Institute Max Planck in Germany. He was investigator in NASA, and later he leaded the Big Data team of the Mundial Bank's Laboratory of Innovation. In January 2017, he renounced to his job in Washington and now he works by giving scientific advice to the company Satellogic. [92]

D.3.2 Work Environment

As stated in [88], the key for the success of this company that provides such a disruptive innovation is the freedom as the way of working. The company looks for very autonomous people as the most important characteristic for the organization. The leading team, states that they know that they are doing something new and better than what already exists, so it is necessary to create new ways to do it. Kargieman recommends that, in order to ensure innovation, it is requested not to fall in love with the ideas, many problems appear when this happens, and it is the way the traditional companies work, so it is a behaviour to be avoided. To prevent this relationship with the ideas is to have a more fluid relationship with them and to focus on the correct results to be obtained, to analyse objectively the ones gotten and to look for the clearly established objectives.

D.4 Market Segments and Product Lines

Satellogic is self-defined as a company focused to unblock the value of the real-time geographical information analysis to improve the daily decision-making process of different companies, sectors of the government or any SME (Small-Medium Enterprise). This objective is achieved by the combination of different capabilities of *Satellogic* that include the reduced cost, the high-resolution of the data as well as the hyperspectral data retrieved. [85]

Hyperspectral data are images that collect and process information along the whole electromagnetic range. These vast electromagnetic range permits the division of the spectrum in different bands that offer different types of information. Some objects and materials leave unique trails through the complete hyperspectral spectrum, and these trails allow the identification of those materials that compose the analysed object. The result of the data obtained is a collection of images in which each of them represents a different spectral band. The set of images combined is known as a hyperspectral cube. [93]

The main device to obtain this type of data was the NASA's satellite EO-1 that integrated the Hyperion sensor, but it was dismantled in March 2017 after spending 17 years in orbit. [84] The dismantling of this satellite translates into the fact that *Satellogic* became the only provider of high-resolution hyperspectral imaging in the world, offering a 30-meter spatial resolution from orbit and with the ability to discern 30 simultaneous spectral bands. These capabilities are not offered by any other commercial or scientific satellite in the EO market.

The use of hyperspectral images can be applied in different EO markets such as agriculture, mining, construction and environmental mapping. Apart from this, *Satellogic*, also looks for the commitment to science by offering free hyperspectral data to open scientific research or other humanitarian projects.

The company's intention for the service offered is to provide not only raw data, but also data products derived from that imagery. *Satellogic* has noticed the importance of the value-added services in the EO market. For that reason, the company is planning to provide a specific solution for each particular EO industry through applications that combine the hyperspectral data with the high-resolution imagery.

After the successful launch of *Fresco* and *Batata* satellites, and its progress in the space sector, the company managed to awake the interest of some companies from the agriculture and oil sectors that had seen the advantages that Satellogic could offer with their EO products. Specially, Satellogic EO products are divided in two types of information depending on the final consumer: Smart data and Industry Solutions. [88]

D.4.1 Smart Data Solution

The type of Smart data offered by *Satellogic*, is presented as the solution to get needed information in real time, and ready to make decisions. This solution differentiates from the traditional monitoring methods that do not offer frequent monitoring, update and immediate information. To confirm these characteristics, Satellogic increments the features of its product adding:

- **High frequency**: the constellation provides high revisit rate in order to better monitor the areas of interest.
- **Affordability:** due of the low-cost structure in contrast to the previous prohibitive prices.
- **Smart data layers**: which allows the superposition of the information in different layers with different types of information in the same area. The advanced data science techniques applied to proprietary and external data give supplemental information.
- **Event analytics**: which permit to receive analytics of the anomalies and changes detected in the defined area of interest.

D.4.2 Industry Solutions

The main purpose of the data delivered by *Satellogic* is to improve the daily decisions that are made every day with the help of the satellite-based information. The combination between high-resolution images with videos and other combined data are expected to offer a forward thinking to competitive industries. The important applications of this technology are thought to be:

- Agriculture.
- Pipeline monitoring.
- Critical infrastructure monitoring.
- Business intelligence.
- Disaster response.
- World new applications.

Therefore, looking at the applications that Satellogic recommends for its products, it can be seen the different EO markets towards which the organization is focused on. According to the previous EO market analysis performed in the State of the Art chapter, *Satellogic'*s customer segment are the markets of:

- Infrastructure and Engineering.
- Natural resources monitoring.
- Location Based Service.
- Disaster Management.
- Energy.
- Environmental monitoring.

D.5 Production System: Lean Manufacturing

Satellogic's main office is located in Buenos Aires, Argentina. The satellites are produced in Uruguay, and the software factory is in Israel. It has business development offices in Palo Alto, and marketing department in Colombia and Canada. [88]

In the department of research and development, the employees work in an environment based on experimentation and innovation. This department concentrates the higher degree of freedom to try new things and ideas which would improve the satellites. Most of the ideas are discarded due to failure in computing tests before the prototype definition, yet the best of them are prototyped and submitted to a process of trial and error starts. [88]

Each new generation of satellites generally takes ten months of development. The instruments are usually developed in three weeks and possess a lifetime limit of three years. However, there are some instruments whose development can take significantly longer. [94]

The *Satellogic* headquarters located in Uruguay, the innovation is applied and studied in the assembling process and the functionalities of the satellites. There is not the same freedom of creation in Uruguay as in the development centre, nevertheless there is a certain degree of flexibility to improve the serial production, the process improvement and the efficiency utilization of the machinery. [88]

The size and weight of the satellites is a key aspect for the launching phase as one space shuttle can launch the amount of 80 of these smallsats at the same time. However, there is a risk in launching them all at the same shot, because a big amount of loss can happen if a failed launch occurs. [88] Satellogic has mainly used Chinese launch vehicles to carry its satellites and as it is explained by *Satellogic*'s CEO, Emiliano Kargieman, it creates some complication in the export process due to the U.S. government restrictions on the exports of satellites and related components to China.

Although the Chinese company, Tencent, had made the most important investment in Series B funding round and Satellogic frequent use of the Chinese rockets Long March, the company states that they do not possess exclusivity with any particular Chinese launcher company and that they do not discard to work with other providers which could offer the same service.

It is important to have in mind that the U.S. government had previously blocked the exports to China, this time to Thales Alenia Space and the European Space Agency accused the United States of using ITAR (International Traffic in Arms Regulations) to block exports to china instead of protecting technology.

D.6 Operational Satellites in Orbit and Future Deliveries

The ÑuSat Earth observation satellites form the Aleph-1 constellation were developed and operated by Satellogic S.A. This constellation was planned to be formed by 8 small satellites, but nowadays it is expected to include around 300 CubeSats. [95].

The constellation formation has been possible after the experience gained through the three first launched prototypes CubeBug-1 and CubeBug-2, which have been nicknamed Capitan Beto and Manolito, respectively. With the knowledge and experience acquired from these satellites, the engineering team of *Satellogic* developed the BugSat-1, Tita, the third prototype, which was the primary pathfinder for the Aleph constellation. It weighs 22 kg and has a mid-resolution camera and amateur radio equipment. [95]. Once the company has verified the functionality of the integrated system for the data acquisition, data downlink, processing and distribution to users and quick tasking of the satellites, the development of the operational satellites of the constellation started.

After the launching of *CubeBug-1 & 2* as well as the *BugSat-1*, the operational satellites would rapidly be designed and developed, trying to include incremental improvements in each of the models. The process used by the organization for the design, testing and development, as well as the materials used, allows the fast manufacturing of the devices. The operational satellites era started with Fresco and Batata, which were both launched in May 2016.

Satellogic developed the sixth nanosatellite and the third operational one named Milanesat, which was launched into orbit in June 2017. Equipped with similar technology than the previous ones, it weighs less than 40 kg and heights less than 80 cm. Placed at the altitude orbit of 500 km, Milanesat spends 93 minutes to go around Earth. With the launch of the third satellite, Satellogic started to be able to offer commercial services to its clients. [96]

In order to continue with the constellation implementation, two more satellites, named Ada and Maryam, were developed. Ada, in honour of Ada Lovelace, considered as the first person to be a computing programmer in history; and Maryam, in honour of the brilliant and well-known Iranian mathematician named Maryam Mirzakhani; conform a pair that make a tribute to important women figures in the world of computing and mathematics. Both satellites were placed into a 500 km altitude orbit in February 2018, to reach the number of 8 satellites in orbit. [87]

Table D.1 presents a summary of the satellites that the organization had in orbit, up to 2018 with the launching dates. [95]

Table D.1: Summary of the launched satellites up to 2018, and the satellites planned to be launched by Satellogic.

Satellogic's Launched and Planned satellites				
Designation	Nickname	Type of Operation	Launch Date	Launching Vehicle
CubeBug-1	Capitan Beto	Prototype	27/04/2013	Long March 2
CubeBug-2	Manolito	Prototype	21/11/2013	Dnepr
BugSat-1	Tita	Path Finder	19/06/2014	Dnepr
ÑuSat 1	Fresco	Commercial	30/05/2016	CZ-4B
ÑuSat2	Batata	Commercial	30/05/2016	CZ-4B
ÑuSat 3	Milanesat	Commercial	15/06/2017	CZ-4B
ÑuSat 4	Ada	Commercial	02/02/2018	CZ-2D (2)
ÑuSat 5	Maryam	Commercial	02/02/2018	CZ-2D (2)
ÑuSat 6, 7, 8	-	Project	Planned for 2018	-

The commercial satellites are all similar in performance and technology to reduce costs and to provide better solutions. Each of them has three cameras: [88]

- **Thermic camera**: which registers images in the infrared and is also capable of detecting variations of a centesimal degree, the humidity of the ground, the amount of petroleum inside a ship or even the energetic efficiency of a building.
- **Hyperspectral camera**: which produces images in 600 bands and offers information about the chemical composition of a factory's spills, specific varieties of some crops or to measure the chlorophyll absorption.
- **Multispectral camera**: which takes images in red, green and blue channels as well as in infrared. This camera is especially useful in applications related with agriculture because it allows to know the different biophysical parameters of the crops.

Apart from the image capturing, the satellites from the Aleph-1 constellation also capture and provide information about physical and chemical parameters from the environmental data, such as the state of a plant in the middle of a crop. [86]

Regarding the physical characteristics of the satellites which are built by *Satellogic,* they are smaller, lighter (weight of 45 kg) and cheaper to produce than the traditional ones. Additionally, they are designed with the objective to offer a higher revisit rate than other constellations and the technology they include permits a ground sampling distance lower than two meters, which is comparable to other expensive commercial satellites like *DigitalGlobe*.

Satellogic's smallsats have several advantages and disadvantages in front of the traditional ones like:

- The **size** provides the advantage of launching multiple satellites in the same rocket without representing a very high cost. The **power energy system** works with the sun through solar panels that are placed round the satellite in the sides of it. When they pass through the dark side of the orbit, where the Earth is between them and the sun, they have a battery that is discharged, and this happens every hour and a half. Therefore, as it happens to every battery, after 6 or 8 months of continuously having this charge-discharge cycle, the device starts to deteriorate; the design life is usually of three years, but maybe 17 years can pass before they deorbit. [97]
- Apart from the simple and cheaper design, *Satellogic's* designers had to cope with the usual challenges of space such as the **temperature difference** that the satellites must experiment. As they spend more or less 90 minutes going around the Earth, they witness opposite temperatures very often being the range from 100 Celsius degrees from minus 100 Celsius degrees. [98]
- The satellites not only are covered of aluminium, carbon fibre, mirrors and lens, but also provided with a propulsion system to change their orbit in case it is necessary. Emiliano explains to Clarin interview that there are no **regulations** about the orbit to use, so the collision probability grows as it increases the number of satellites in it. There are some organizations whose objective is to monitor the movement of the satellites, and by orbit prediction can detect a collision probability which is informed to the operator of the satellite in danger. This propulsion system is need in case a collision scenario may occur, in order to correct the trajectory. [94]

According to Satellogic's plan of action, the organization will finish 2018 with 16 satellites, and reach the number of 300 spacecrafts in 2020. To achieve it, the organization plans to produce and launch twelve more satellites during 2018 and another sixty during 2019. [94]

D.7 Online Platform: Microsoft Agreement

In a public interview, the founder of *Stellogic*, stated that it is a mistake to think about the current Earth Observation market and look for a space into it. As he explained, there a growing number of companies that produce satellites and constellations to provide the service of the Earth Observation. The plan, instead, is by lowering the acquisition data cost by several orders of magnitude, combined with rapid revisit rates and data analysis tools, is what will make the difference with other competitors, his literal words were: "*we'll essentially open up completely new markets for Earth observation data and we'll make this data part of daily decision-making for every industry in the planet". [89]*

Satellogic's business model has two different phases which are: to continue making the low-cost satellites and keep on with adding incremental improvements in each of the launchings, while developing the application platform to allow the future clients to obtain all the information from their images and the parameters gotten by the first satellites. [88]. Within the agreement which they reached with Microsoft in November 2017, *Satellogic* could start counting on Azure, Microsoft's Data Centre, to intelligently process and analyse the information captured.

Ezequiel Glinsky, Microsoft's manager of new businesses, stated that the fact that Satellogic worked with open source as it is Linux, had been a challenge for them and have changed their mind about it in the last months. The real problem that Azure had to solve was to cope with the amount of information obtained by the satellites and how to transform this data into useful information to improve the decision-making process of governments, companies or particulars.

From the work performed using artificial intelligence (AI) as well as Machine Learning, processes can be learned from the collected data and find the best way to use the natural resources, improve the productivity of some industries or monitor the regional economies growth.

The artificial intelligence algorithms are used to identify objects and perform an automated classification. The work is focused on looking for the gradual changes produced in an image to detect changes in a defined area, such as the cut of a group of trees in a zone. Some may think this tools can have military applications, but Kargieman, *Satellogic's CEO,* states a firm position about that saying that "*our company's culture and objective is against this military application, the objective is to improve people's lives and not to learn how to kill each other".* [94]

Regarding the Azure Microsoft's platform, in its website is self-defined as an integral service set in the "*cloud*" used by the professionals and IT developers to create, implement and manage applications through their global network of data centres. The platform offers services of integrated tools, DevOps (Development and Operations) and a marketplace which would help Azure customers to create anything in an efficient way.

Related with the products offered by the platform, there are solutions for processes, connectivity, storage, web and mobile, containers, database, analysis, Artificial Intelligence and Machine Learning, Internet of Things, Integration, Security and Identity, Tools for developers and Administration tools.

The platform gives different options for the development regarding the Operating System (OS), windows or Linux; and different programming languages, such as .NET, Python, Java, or PHP, among others. [99]

D.8 Financial Status

The shareholders of the company do not own public information, however, according to *Satellogic's CEO,* they are composed by the founder partners, investors and employees. [85]

In [85], appear some lines of information which remind the readers to the words of Matt Ocko, partner of the venture capital Data Collective funds, saying in an email that "*An important aspect for the increased investment in the space sector, is due to it is believed that Moore's law has arrived to the space".*

From the start of its activities in 2010, Satellogic has been well received in the world of private capital. Until now, Satellogic has received four investment rounds, in different stages. The most important one was closed in June 2017 for 27 million dollars and it was leaded by Tencent, the Chinese giant which also invested in Uber, Snap Inc. and Tesla. [87]

According to [100], some information about the rounds of investment and the different investors of Satellogic has been extracted. This information is found in Table D.2.

Table D.2: Summary of the investment Rounds for Satellogic.

Satellogic's Rounds of Investment			
Transaction Name	Date	Number of Investors	Money Raised
Seed Round	01/09/2013	3	$ 2M
Series A	15/03/2015	4	-
Venture Round	01/05/2016	1	-
Series B	23/06/2017	3	$ 27M
ÑuSat2	Batata	Commercial	30/05/2016
ÑuSat 3	Milanesat	Commercial	15/06/2017
ÑuSat 4	Ada	Commercial	02/02/2018
ÑuSat 5	Maryam	Commercial	02/02/2018
ÑuSat 6, 7, 8	-	Project	Planned for 2018

The investors of these four investment rounds are:

- Pitange Fund
- Tencent Holdings
- CF
- Nxtp Labs
- Endeavor Catalyst
- Valor Capital Group
- Santiago Pinto Escalier
- Ariel Arrieta

From the previous list of investors, only two act as lead investors, which are Tencent Holdings, and Valor Capital Group. [101]

Appendix E: Case Study - Deimos

This appendix will present the Case Study of Deimos. The space delegation of this company carries out activities such as Mission Analysis, System Engineering, Guidance, Navigation and Control, Attitude and Orbit Control, Ground Segment Systems and On-board Software Systems. This chapter is divided into History and Overview of the company (section E.1), Business Statement and Philosophy (section E.2), Ownership and Employees (section E.3), Partnerships (section E.4), Earth Observation Market Segments and Requirements (section E.5), Applications (section E.6), Production System (section E.7), Operations (section E.8), Online Platform (section E.9) and Financial Status and Risks (section E.10).

E.1 History and Company Overview

Elecnor Deimos was founded in 2001, aiming to develop and provide high-tech systems and engineering solutions. This company, based in Tres Cantos, Spain, is the technology branch of *Elecnor,* one of the Spanish leading companies in engineering, infrastructure and construction projects, and a prominent investor in renewable energy, environmental infrastructure and space. The company defines its inspiring principles as excellence, commitment and innovation. [102]

Elecnor Deimos develops activities in the fields displayed in the following lines:

1. ***Space:*** Offering expertise across the entire value chain in satellite systems.
2. ***Aeronautics:*** Turn-key operational systems in the areas of Radio Navigation Aids, Surveillance and Communications.
3. ***Maritime:*** Offering tailored engineering solutions, tactical communications, command and control systems and satellite imagery for maritime applications.
4. ***Transport:*** Developing a customized management and fleet exploitation support systems and other solutions for the railway sector.
5. ***Industry & Utilities:*** Providing solutions for cost savings and increased efficiency.
6. ***Telecom & Media:*** Offering technologies for business improvement.

Focusing on the Space branch of *Elecnor Deimos,* it participates in the majority of ESA programmes, providing systems engineering, ground segment, mission analysis and design, and onboard solutions, as well as satellite integration, in the fields of Science and Exploration, Satellite Navigations, Earth Observation, Space Situational Awareness and Launchers. [103]

The following lines aim to be an introduction to the products and services that the Space division of *Elecnor Deimos* offers to its commercialisations; nevertheless, these services will be explained in deeper detail in the sections that are to be introduced.

1. ***GS4EO:*** A complete suite of ground segment products.
2. ***FLY4EO:*** Full orbit monitoring and maintenance capabilities.
3. ***PLAN4EO:*** Multi-spacecraft mission planning module.
4. ***ARCHIVE4EO:*** Multi-mission component in charge of the archiving, storage and inventory functions.
5. ***PROCESS4EO:*** Data-processing module.
6. ***USER4EO:*** Multi-mission web-based service for EO imaging request.

Additionally, *Deimos Space* develops the following projects, amongst others:

1. ***REDSHIFT:*** Revolutionary Design of Spacecraft through Holistic Integration of Future Technologies.
2. DEIMOS-2.
3. ***EXOMARS:*** End-to-end mission analysis and design: from launch to Mars.

In order to develop all this tasks and projects, *Deimos Space* counts with a team of more than 200 engineers, and possesses divisions in multiple countries (besides Spain, in Italy, Romania and UK). [104]

E.2 Company Business Statement and Philosophy

E.2.1 **Business Idea**

From the time being, Deimos Space in the Earth observation business is distributed in five main segments: satellite systems, flight segment, real-time systems, ground segment systems and direct reception stations. With all of this, it has participated in very successful projects such as Deimos-2 which is based on an agile European satellite capable of providing sub-metric and multispectral images. Currently, one of the main objectives of the company is the expansion and diversification of the activities on commercial space programmes outside Europe while consolidating the geographic expansion in Europe by means of creating subsidiaries in Portugal, Romania, Italy and England.

The main customers of a company in this sector are private companies, space agencies or governments. For the present case, the key clients are governments, space agencies (NASA, ESA, but especially the second one) and private companies of different sectors such as maritime, defence, petrol extraction, gas and satellite operators.

The competition in this market is strong and very stressful due the continue innovation in the technological matter and currently even in the business models. Nevertheless, Deimos Space has an outstanding suite of own products and services which along with the successful business strategy of Elecnor Group based on the activities' diversification (founded in 1958) allow it to provide a unique solution within the Earth observation market. In this context, clients find in Deimos Space a great collaborator and provider due to its wide and long expertise with more than 18 years (founded in 2001) in Earth observation projects and the flexibility and scalability of its products and services that can fit better with customers' needs.

E.2.2 **Business Statement**

The business statement exposes the mission, vision and values of the company. For Elecnor Deimos Space:

Mission: Elecnor Deimos Space mission is to provide engineering solutions with leading-edge technology and innovative and high-quality products and services contributing to the technological and economic progress of the markets in which it operates and giving added value to its customers.

Vision: Elecnor Deimos Space is addressed to reach the long-term success through a continue and sustainable growth in order to be capable of becoming a real multinational corporation.

Values:

- **Reliability:** its trajectory, management and daily work establish the basis of the security and guarantee to its customers through the compliance of the objectives and commitments undertaken.
- **Commitment and effort:** the main characteristics of people working at Deimos Space is their professional loyalty and dedication to work.
- **Customer orientation:** as it has been defined in its mission, the willingness to add profitable value to the clients is a maxim.
- **Solvency:** its capacity to apply the most effective and top technology in its activity development is a must.
- **Innovation:** R&D investment is a strategic focus since the innovation is understood as the most profitable engine for the progress.

E.2.3 **Business Objectives**

The current Elecnor Deimos Space strategic plan is focused on achieving the following objectives:

1. Consolidation of the activities within the ESA's projects following the Group's strategic line.
2. Expansion outside Europe through boosting the activities on commercial space programmes.
3. Prioritize satellite applications for Earth observation and satellite navigation.
4. Foster the downstream market in order to apply Big Data technologies for the development of satellite applications for end users.
5. Transfer technology to other sectors of activity of the Elecnor Group enhancing possible internal agreements.
6. Enhance the efforts in satellite assembly activity field to define a complete value chain for the space programmes.

E.3 Ownership and Employees

Elecnor Deimos Space is assembled in a similar organizational structure as Elecnor Group, except by the Enerfín (wind subsidiary of Elecnor), Celeo (energy transmission sector) and the network departments). This Elecnor Group structure can be seen in Figure E.1.

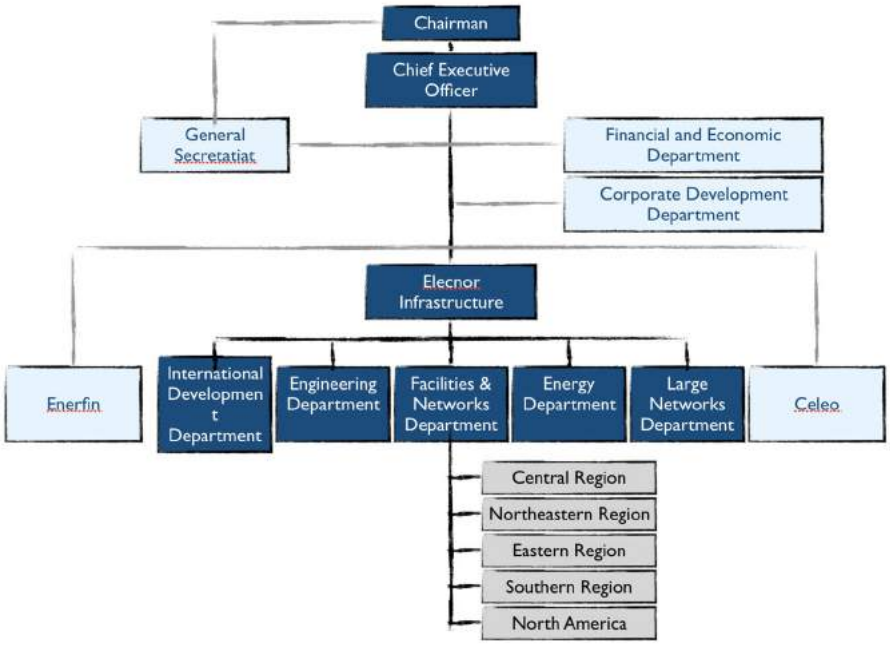

Figure E.1: Deimos organizational structure.

In Elecnor Deimos, the same structure exists based on a board of directors exposed here below managing 326 employees around all its subsidiaries (38% female and 62% male, by following the company's gender equality policy and diversification) .[105]:

- Chief Executive Officer (CEO): Miguel Belló Mora.
- **Finance director:** Ignacio Yurrita Meiras.
- Human Resources (HHRR) director: Inés Hoyos Asensio.
- Production, Commercial and Marketing director: Ignacio Turne.
- **Quality director:** Luís Castillo Zugasti.
- IT and Data Processes director: Jesús Laguna.

E.4 Partnerships

Deimos Space has currently the following active partnerships [106]:

- ***GUDNUS:*** company that provides efficient solutions for energy engineering projects. Its partnership is addressed to provide thermography services by using a self-developed tool developed in the project APPIDE (Automatic Photovoltaic Plant Inspection and Data Exploitation) taking profit of long and wide expertise of GUDNUS in thermography services applying drone technology.
- ***ORBEX:*** company that develops an innovative launch vehicle for small satellites called Prime. Deimos Space has become an investor of Orbex for the partnership for satellite launches.
- ***ESA:*** European Space Agency, public agency that carries out a lot of missions into their different space programmes. For that purpose, ESA has many industrial partners, one of which is Deimos Space.
- ***Mars Sample Return:*** this is a project carried out in collaboration by ESA and NASA which is addressed to bring to the Earth different samples of Mars. In this project, there are many partners involved such as Thales Alenia Space, GMV, OHB and Deimos Space, apart from the public agencies.
- ***Neptuno Project:*** project for the CDTI (from the Spanish Centro para el Desarrollo Tecnológico Industrial) within the European Union that face the main challenges of maritime surveillance. Deimos Space is leading this project with partners such as Aeorum España and DHV (advanced space technology of Malaga).
- ***Discoverer project:*** innovative project that is addressed to revolutionize Earth observation by operating the satellites at much lower orbits than usual. In this project, a consortium of many partners was defined in which some them are: Deimos Space, Gomspace APS, Universitat Politècnica de Catalunya, Euroconsult, University of Stuttgart and so on. For more details, go to [107].
- ***Dauria Aerospace:*** its partnership is aimed to develop Deimos Perseus which will be the first satellite constellation to provide frequent images of the entire Earth.
- ***Mohammed Bin Rashid Space Center (MBRSP):*** partnership funded by the International Partnerships in Space Programme from the UK Space Agency with the objective to automate the geospatial information that will feed the initiative Smart Dubai that will help to plan and monitor the urban transformation. All this within the SAFIY project.

E.5 Earth Observation Market Segments and Requirements

The main customer segments are the following ones:

- Agriculture
- Defence and security
- Disasters monitoring
- Maritime surveillance
- Infrastructure management
- Utilities
- Mining
- Research

As an additional and more concrete comment, Deimos Space provides solutions to the following customers [106]:

- ***UrtheCast:*** In 2015 it purchased Deimos-2, which is currently being operated by Deimos Imaging.
- ***ESA and NASA space programmes:*** Deimos Space participates in many different projects from ESA and NASA, providing multiple solutions according to the main matter of the mission.
- ***Deimos Imaging:*** Currently, subsidiary of the Canadian company UrtheCast, which purchased Deimos-1 in 2007.
- ***Open tenders:*** Deimos space won the leadership of the *Neptuno* project for the CDTI of the Ministry of Spain, within the European Union.
- ***SATRECI:*** Focused in the flight market segment.
- ***DMS:*** A company which is part of the ground segment software.
- ***VERTEX:*** Which is an antenna manufacturer.
- ***KOSMOTRAS:*** A company based in the launching segment.
- ***Elecnor Group:*** Focused on security and multiservice network.
- ***Spanish Government:*** Which funds the company through the Mining funds.

E.6 Applications

Regarding *Deimos'* main activities and applications of their commercialized products, the first topic that is going to be introduced are the main resources that the company owns so that this final product might be developed. In order to do so, Table E.1, summarizes and plots a distribution of the company's key resources:

Table E.1: Deimos resources and capabilities

Deimos Key Resources	
Financial	Elecnor Group Funds
	Public Space Agencies Programmes
	European Open Tenders
	Internal Assets
Physical	Subsidiaries in 5 countries (buildings)
	Ground Systems
	Leading-edge Technology
Technology	Facilities IT-controlled
	Antennas for satellites surveillance
	Gs4EO suite of products and services
	Business strategy based on diversification from the activities transferred from Elecnor Group
	Space Technology knowledge
	Capacity to innovate
Reputation	Elecnor Group Support
	Successful projects in European Union
	Strong alliances
	Strong presence in public space agencies programmes
Human	High-qualified staff
	Commitment
	Easiness in family conciliation
	Great opportunities for career development

Extracting some conclusions from Table E.1, it might be stated that Deimos main capabilities are the following ones:

- Strategic geographical locations in Europe.
- Capacity to establish new subsidiaries out of Europe.
- Full-stack solution for ground segment systems.
- Capacity to develop, operate and deliver fully integrates, tested and operated satellites.
- Superior facilites in Deimos Castilla La Mancha.
- Continuous plan of development to reduce costs, and thus, service prices.
- Efficient operations management.
- Great customer experience provider.
- Real-time systems provider.
- Elecnor Group expertise for the business strategy based on activities diversification.

Therefore, the main distinctive capabilities of Deimos Space is to be able to develop satellites through its superior facilities in Castilla La Mancha, Spain, in a very efficient, low-cost and optimum way, and afterwards, test and operate them, being able to deliver fully operative satellites. Its continuous plan of development allows them to reduce costs and increase quality through leading-edge technology, having the capacity to establish new subsidiaries out of Europe in order to achieve one of its business objectives, which is international expansion. Based on all this information, Deimos competitive advantage might be defined as an efficient end-to-end satellite systems developer, integrator and operator.

When it comes to defining the company's value proposition, it would be characterized through the following products and services:

- Feasibility and risk assessments.
- Different type of data to resell.
- Ground Information Systems (GIS), such as antennas for satellite monitoring and data reception.
- Efficient end-to-end satellite systems developer, integrator and operator.
- Launching services through Orbex partnership.
- 4EO suite of products within VAS.
- High and very high-resolution imagery technology.

E.7 Production System

Within the development of this section, the value proposition of Deimos Space will be decomposed, so that the main areas of activity, products and services are exposed. Afterwards, some considerations about how the products are developed will be introduced as well.

E.7.1 **Main Areas of Activity**

- ***Space Consultancy:*** Studies mainly for the feasibility of any satellite in technological and business terms.
- ***Data Reception and Distribution:*** Deimos is the owner of three antennas which monitor different satellites.
- ***Data Reseller:*** Satellite data or other data which is sold to third parties.
- Hardware and software developer.
- Ground Information Systems (GIS) and downstream services.
- ***Value Added Services (VAS):*** It generates its own products.

E.7.2 Products and Services

- ***GS4EO:*** Set of ground segment systems that can be operated either separately or simultaneously in order to provide a full-stack unique solution.
- ***FLY4EO:*** Product to analyse the Flight Dynamics Systems (FDS) within the previous set of products. It allows to determine and control the orbits and monitor the space debris.
- ***PLAN4EO:*** Module to plan the mission in an intuitive and simple way that can be integrated with other modules or products from the gs4EO suite.
- ***ARCHIVE4EO:*** Module based on the archiving and storing data and stock of the mission into a repository.
- ***PROCESS4EO:*** Module for data processing.
- ***USER4EO:*** *W*eb service for multiple missions which allows to ask for satellite images.

E.7.3 Deimos Value Chain Analysis

So that Deimos production system might be better understood, it is going to be presented through image E.2, which is a representation of the company's value chain.

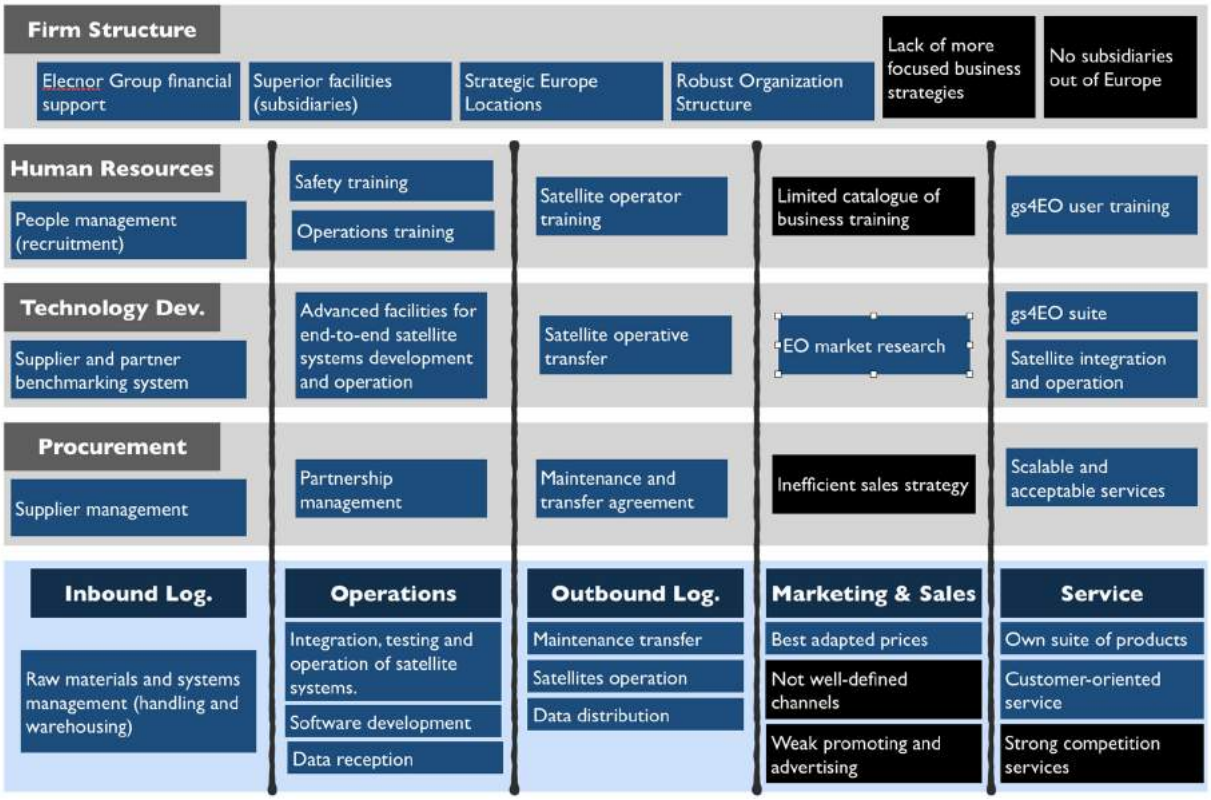

Figure E.2: Value Chain analysis for Deimos Space.

E.8 Operations

Considering the main customer segments and the main sectors of activities of the company, *Deimos Space* presents the following portfolio within its value proposition of products and services:

- Feasibility and risk assessments.
- Different type of data to resell.
- Ground Information Systems (GIS), such as antennas for satellite monitoring and data reception.
- Efficient end-to-end satellite systems developer, integrator and operator.
- Launch services through *Orbex* partnership.
- 4EO suite of products within VAS.
- High and very high-resolution imagery technology.

Deimos Space has a product strategy distributed between market penetration and product development, since the EO market is a consolidated market, but in addition to offer the basic services covering the customer needs, they develop their own suite of products adding value to the market and trying to achieve the diversification in the market.

E.9 Online Platform

Regarding *Deimos Space* solutions delivery, the company owns an interesting enough online tool. They make use of KORE. KORE is a cloud-based land management platform, developed by Scottish specialists SoilEssentials Ltd in collaboration with Deimos Space UK. The platform was presented on November 2017, in Hanover, Germany. The companies embarked the development of this project supported by the European Space Agency, when the opportunities and advantages that the wider availability and lower cost of Earth Observation data represented in the agriculture field were starting to be acknowledged. [108]

KORE combines Earth Observation imagery from a variety of sources, including ESA's Sentinel series of satellites, to guarantee the availability of remote-sensed data. This is a web-based precision farming toolbox, to manage variation through space and time with and interface where software, hardware, services and research work together as an innovative land management solution.

BEsides the KORE services, Deimos' ground Segments are based on the gs*4*EO r products, that its combination make possible a customized ground segment. Although all the gs*4*EO products can be used as independent applications, they can work in a coherent and synchronized way. These products are commercialized by the company to third parties, as well as used by the same company. The main characteristics of the gs*4*EO suite are:

- State-of-the-art.
- Proven operationally at ESA and Deimos missions.
- Flexibility, scalability and user friendly.
- Designed for maximising spacecraft return.
- Minimum operational costs thanks to advanced automation.

The different modules of the suite are:

- plan*4*EO, for mission planning.
- archive*4*EO, archive and catalogue.
- fly*4*EO, flight dynamics.
- process*4*EO, image processing chain.
- control*4*EO, mission control system.
- monitor*4*EO, monitoring and control.
- track*4*EO, ground station.
- calval*4*EO, calibration and validation.
- user*4*EO, user services.

Its modular design allows the gs*4*EO suite of ground segment products to be used to customize the ground segment according to the customer's requirements. The various individual products can be assembled in different ways to implement different deployment configurations. This modularity also provides extraordinary flexibility in order to accommodate more than one EO mission within an individual ground segment.

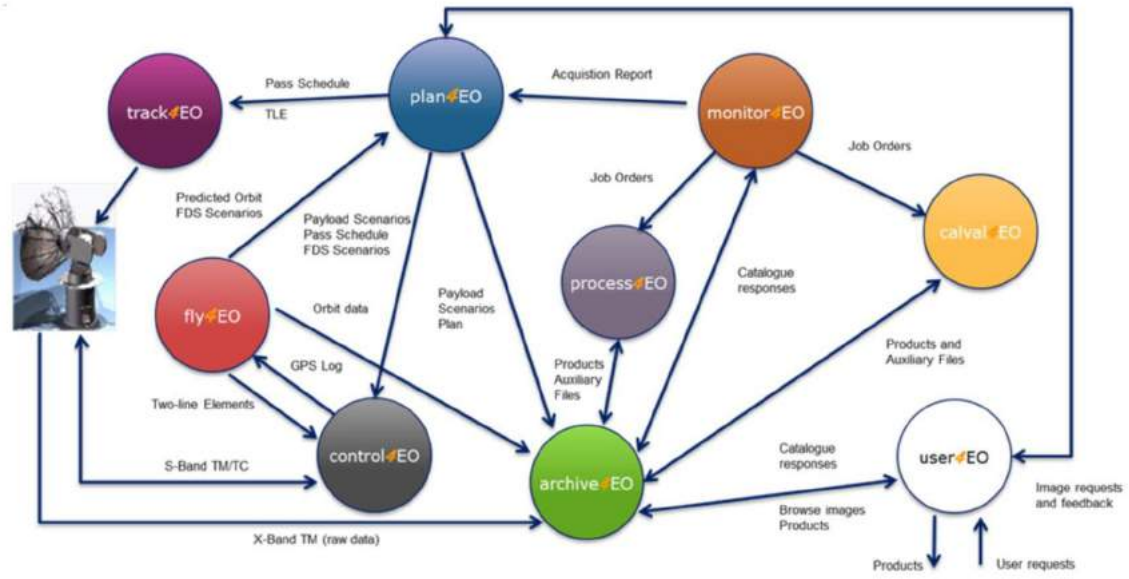

Figure E.2: *Gs4EO services and connections, extracted from [109].*

E.10 Financial Status & Risks

E.10.1 **Financial Status**

In order to start with the financial status of *Deimos Space* the first subject that is going to be treated is the Financial Objectives that the company aims to achieve. It is mainly the pursuit of increasing the revenue potential of *Deimos* through its international expansion and consolidation of European activities. At the same time, this goal is aimed to be achieved through:

- Establishing at least 3 different subsidiaries outside Europe within a period of 4 years starting from 2019.
- Increasing its revenues by 7% during the first year of the period considered (2019-2020).

E.10.2 **Risks**

The main risks that *Deimos* might have to face during its development activities are listed in the following lines:

1. Insufficient investment capacity to expand the business.
2. Obstacles during the innovation and technology development process.
3. The governments limit the number of funding with strict requirements and/or the investments are not used in a proper way.
4. Misunderstandings between the different funding governments.
5. The downstream market is raised up to the same level of the upstream market.
6. EO market in the rest of the continents evolves faster than the European market.
7. Entrance of new players with low-cost solutions.
8. Obstacle to move from public sector to private sector.

Appendix F: Case Study - Spire Global

This Appendix will present the Case Study of Spire Global, which is a space to cloud data analytics private company, U.S. based. It provides the most advanced aviation, maritime and weather tracking in the World through their satellite data algorithms. This is possible thanks to a fully owned and developed constellation of Nanosatellites, a global ground station network and continuous operations that bring real-time Earth coverage. The information is organized under History and Overview of the company (section F.1), Business Statement and Philosophy (section F.2), Ownership and Employees (section F.3), EO Market Segment and Requirements (section F.4), Production System (Section F.5), Operations (section F.6), Satellite Payloads and Applications (section F.7), Online Platform (section F.8), Partnerships (section F.9) and Financial Status and Risks (section F.10).

F.1 History and Company Overview

Spire Global, Inc., formerly known as *Nanosatisfi Inc*., was founded in August 2012 in Delaware. It was co-founded by International Space University former students Joel Sparks, current Spire Global CTO, Jeroen Cappaert, current Spire Global CTO, and Peter Platzer, current Spire Global CEO [110] (further information in section F.3). It was the latter one who, while at the Singularity University from NASA in 2009 realized that there was a ”tremendous *amount of change happening in the space industry”*. He later organized this trend in the sector into a ”tri-*factor of change”.*

The first factor of change are the shrinking government budgets. There was a need for other sectors, like the private one, to step in as the government budgets were getting more and more squeezed. The second one is the emergence of billionaires in space. These individuals want to leave a legacy by putting their reputation, network, capabilities and net worth on the line and fill the gap left in the previous point. Finally, the third factor is the emergence of new technologies following the Moore’s law. The Nanosatellites are about 3 orders of magnitude cheaper and lighter than traditional satellites, can carry the most modern technology and are more launched than any other satellite form [111].

Thus, the industry was changing from a slow and government dominated to a more versatile, innovative and private companies dominated. With little innovation, their technology was getting obsolete and it was taking enormous amounts of time and money to launch satellites.

That sparked him to go to the International Space University to obtain a MSc. in Space Science and Management. There he met the later co-founders of Spire Joel Spark and Jeroen Cappaert. From looking onto the nanosatellites new technology and their business ecosystem they decided to start a company. They based it on some principles that nowadays can be seen as their 3 main pillars; they *”collect data where nobody else can”*, they *”collect data not the size of sensor but the number of sensors creating value”* and they *”collect data where the sensors are programmable and re-programmable by software to really bring Moore’s Law to space” [112]*.

Nanosatisfi started then with the building of a prototype nanosatellite that was intended to be a platform to approach space to students in terms of accessibility and costs. This was called the *ArduSat*, as it was based on Arduino technology, and started to be founded thanks to the crowd-funding website *Kickstarter* [110]. With an initial goal of USD 35K intended to build the 1U CubeSat, the amount was raised to USD 106.33K by the end of the funding period in July 2012 and supported by 676 backers. Soon after that, Spire raised USD 1.2M from individual angel and venture capital investors on the *AngelList* platform for start-ups that helped them build the company [113]. They moved to the hardware incubator Lemnos Labs in San Francisco and founded by themselves its launch pad [114].

Eventually the two *ArduSat*, 1 and X, (see sections F.6 and F.7) were launched on board of the *H-2B-304* rocket from the Tanegashima Space Center in Japan to the *International Space Station* (ISS) on August 3, 2013. They were deployed from there on November 19, 2013 at about 400km from the Earth surface and re-entered the atmosphere on April 15 and 16, 2014 respectively. Due to the success of the program, Nanosatisfi launched the next generation of ArduSat, the ArduSat 2 on board of the Antares-120 to the ISS on January 9, 2014. This 2U CubeSat was then deployed on February

28, 2014 at an altitude of 400 km above the Earth surface and re-entered the atmosphere on July 1 of the same year

The crowd-funded program of the ArduSat made Platzer gain the recognition by the Obama administration as a ”Crowdfunding Champion of Change” in 2013, with the ArduSat 1 and X being the first ever crowd-funded satellites in orbit [110]. However, the main idea Sparks, Cappaert and Platzer had in mind was to develop the most accurate weather forecast and they never lost sight of that [112]. On this direction they launched their 4th satellite on June 19, 2014, the Lemur-1. This is a 3U CubeSat intended for technology demonstration and EO, with an Electro-optical imaging system of 5 m resolution and an IR imaging system of 1 km resolution payloads. It was intended to assess for meteorological, aeronautical and maritime potential commercial markets and had approval from the National Oceanic and Atmospheric Administration (NOAA). The CubeSat orbits with a perigee of 612 km and an apogee of 697 km [110].

Soon after the launch of the Lemur-1, on July 28, 2014, Nanosatisfi changed its name to Spire claiming that the new name and web presence were *”emblematic of the energy and enthusiasm that we put into our technology and into the relationships that we have developed with our customers, and as a team”. At the same time Spire communicated that their growth process is doing well with a new USD 25M series A closed funding deal that raised their total fundings up to USD 29M.* This investment was led by RRE Ventures and had participation from other investor such as Moose Capital, Quihoo and Mitsui & Co. Global Investment. That same year Spire opened a second office in Singapore, a country which government in the eyes of Platzer *”spends a lot of effort to create economic diversity and economic growth, thinking about industries that don’t require large amounts of people and land” [112].*

The beginning of 2015 came with the announcement of the next generation Spire Global CubeSats, the Lemur-2 (see section F.7). This 3U CubeSats will create a constellation that, at that time, was able to collect meteorological data through GPS-RO (Stratos payload) and ship tracking data through AIS (Sense payload). This would help to provide a more accurate and reliable weather prediction and fleet efficiency, safety, voyage and fuel management improvement for shipping companies. With an expected lifetime of about 2 years, the Spire constellation was safe to be constantly technologically updated. The first 4 units of the Lemur-2 were launched and deployed on September 28, 2015 from India at an altitude of 640 km above the Earth surface. Since then until February 1, 2018, 77 Lemur-2 have been launched with this configuration, even though the orbital altitudes have ranged from 400 km to 590 km. However, from May 21, 2018 a new additional payload has been incorporated for airplanes track through ADS-B (AirSafe payload).

During the 2015 summer, Spire opened a third global office in Glasgow, UK, becoming their first European office. It would support the design, development manufacturing and data management of the company CubeSats. The announcement came supported with a GBP 1.9M grant funding from the Scottish Government and the Scottish Enterprise [115]. A few days later, on June 30, 2015 Spire announced a USD 40M Series B investment funding led by Promus Ventures. It also involved already-known investors RRE Ventures and Lemnos Labs and new faces like Bessemer Venture Partners and Jump Capital [116].

The year 2016 stated with the opening of the 4th Spire Global Office in Boulder, Co. While the Lemur-2 was being launched and ground stations were built along the year, the NOAA awarded Spire Global with the first-ever satellite data contract to a private industry company in September. With it, Spire joined the US government to acquire weather data from space in order to improve weather forecast with an award worth USD 370K. It became part of the government’s Commercial Weather Data Pilot program [117].

Spire finished the 2016 year announcing on December 6 the space-based global aircraft tracking service AirSafe. By using ADS-B this new Lemur-2 payload would capture and provide location of most international flights, as they would need to provide updated flight information every 15 minutes. This was an International Civil Aviation Organization (ICAO) mandate that would be effective by November 2018 [118].

On March 6, 2017 Ball Aerospace and Spire Global announced a collaboration in association with the National Geospatial-Intelligence Agency (NGA) to improve Maritime Domain Awareness (MDA) in the arctic. Spire's constellation will collect vessel tracking data over the Arctic. This data is integrated into Ball's cloud-based data analytics architecture with other external data to create accurate and near real-time information of maritime activity and vessel behaviour in the Arctic.

Later that year, on November 6 Spire Global announced the opening of their fifth office and the closing of a Series C funding worth USD 70M in order to continue their global expansion. The office would be in Luxembourg and would serve as the company's full-service European headquarters. The financing round was led by the Luxembourg Future Fund, which also became a Spire global shareholder, and included Empiricus Capital. With this Spire aimed to increase access to global talent while establishing in a country that provided support, commitment, and expertise to NewSpace.

February 1, 2018 saw how the UK Space Agency awarded about GBP 4M to Spire Global in order to demonstrate space technology including parallel supercomputing. This particular technology was to serve as a core component for future computationally intensive missions.

During the beginning of March 2018 Spire made big steps towards their satellite-based aircraft surveillance platform with two announcements. Firstly, the signing of a Letter of Intent with INDMEX for the use of the collected ADS-B data for Airport and Airline Collaborative Decision Making (CDM). Secondly, Spire Signed a Memorandum of Understanding with Airbus Defence and Space in order to contribute with Spire's ADS-B data to the Airbus Surveillance Digital Eco-System.

Spire saw their quality satellite development recognized and rewarded with a partnership with DHV Technology to offer their solar panels to the rest of the space industry. They would build and sell the double deployable panels.

The company was kept busy with new partnership announcements like, in April 24, 2018, when Spire Global and Esri started a partnership which would integrate the latter's satellite datasets into the former global user ArcGIS platform.

However, not everything was a piece of cake. In September 27, 2018 a Congressional Report issued by the NOAA in reference to the Commercial Data Weather Pilot reviewed the contractors of the program in round 1 by 2016 and their delivered data. Spire Global delivered a first dataset with quality issues in background noise, uncertainty in satellite position and clock offsets. Spire was required to fix the issues and delivered new improved data only on the final week of the delivery period. It showed some agreement with weather model outputs but was inconsistent. The data was not enough for NOAA to make statistically significant conclusions, leading to a reduction of Spire contract award amount to USD 87.3K. This meant that the company had to de-obligate the remaining USD 282.7K of the initial contract [119].

Nevertheless, the NOAA awarded Spire again with a contract for the round 2 of the program a few days before the Congressional Report, on September 17. The new contract aimed one more time to evaluate the quality of the weather data from the GPS-RO satellite companies and readdressed some issues observed in the round 1. Spire had been awarded with USD 1.425M and has time until July 31, 2019 to deliver the data.

On December 11, 2018 Spire announced at The Morgan Stanley Space Summit in NYC that their constellation would be the first ever to use ESA Galileo GNSS satellite constellation signals to perform radio occultation, or GNSS-RO, for weather sensing. The Galileo GNSS system will be fully operational with 30 satellites in 2020. This will enable Spire to harvest about the 25% of the GNSS-RO profiles available, making the company unrivalled. It also highlighted Spire's capability and flexibility to product satellites and update their software and hardware [120].

F.2 Company Business Statement and Philosophy

Spire Global Inc. defines its mission as:" Our mission is to uncover data and build systems that fundamentally improve the work and lives of the people on our planet. The things we do may create sweeping shifts but we don't do change for change sake - we do things that truly matter" [121].

The Global Trends in Small Satellites [122] defines the organization's missions as to provide "*unique data for any point on Earth in near real time to provide competitive advantages for organizations in areas like global trade, air-traffic, weather, shipping, supply chain, illegal fishing, and maritime domain awareness*." The same report also states Spire's goals as to "*aspire to build and operate the first commercial weather satellite network*".

As previously stated in section F.1, the founder and CEO of Spire Global mentioned that nowadays the company is based in 3 highlighted pillars; to *"collect data where nobody else can"*, to *"collect data not the size of sensor but the number of sensors creating value"* and to *"collect data where the sensors are programmable and re-programmable by software to really bring Moore's Law to space" [112]*.

In their web page Spire Global emphasizes on the value creation and its measurement. Understanding it as the *"cash flow per employee times the number of people affected by products"*, Spire thinks about value in a holistic way. They state that a one-dimensional metric is not enough to measure it, putting examples in their Stratos and Sense products, which reach every part of the economy through weather and shipping respectively. They also state that Spire is *"measured by impact"* and that it is a *"data driven organization"* because *"if you can't measure it, you can't improve it"*.

Platzer described Spire's unique company culture as one which differs from a traditional approach and tries to inspire people. He claims that people need have changed thanks to better economic environments and they nowadays seek for autonomy, mastery, and purpose. This has become an anchor principle in the company as they expect employees to drive for excellence through relentless growth, achieving mastery. The area where they master is self-chosen, providing autonomy, which is spurned with resources and evaluated [112].

Spire website also hosts a section in which the culture of the company is explained. They relate the purpose, mastery and autonomy drives with how they can be found at the company and how they encourage the employees to seek them. They align personal purpose with Spire's missions and vision, measure mastery through reliability of on-time deliveries and encourage autonomy through ownership of the employee's tasks. Instead of traditional managers they implement a system with coaches and captains. The former are great people leaders who mentor their subordinates (called *"players"*) through interpersonal skills to achieve others personal grow, while the latter are the technical leaders responsible for the driving results [123].

Instead of performance reviews Spire caries out quarterly coaches discussions every 3 months in which they discuss purpose, autonomy and mastery growth with their players [123]. This discussions involve questions such as *"how are your autonomy, mastery and purpose doing?"*, *"what do/don't you enjoy how to do more/less of that?"* or *"where do you see yourself in 5 years?" [112]*.

Regarding all discussions above, Spire defines its people as self-driven and growth oriented who have a relentless desire for self-improvement, collaborative across boundaries and time zones as the company is decentralized and with a high emotional quotient, able to recognize emotions, communicate effectively and adaptive to social changes.

Connected to this unique culture, Peter Platzer earned a reputation of being the boss who has never fired anyone. However, this wasn't entirely true as the company has a zero tolerance towards employees doing inappropriate, illegal or insubordinate actions. This has led to a few rare dismissals. Nonetheless, the culture of the company encourages them to find a solution to align the company mission with the worker purpose, but if it is not possible they always agree to part ways [112].

F.3 Ownership and Employees

Spire Global claims in its website that they do not have a common organization chart, following their philosophy of personal development through coaches and captains. All their members work in critical business areas that ultimately support the customers, placing them at the top of the chart. Then the stack is distributed in a way that all its parts are crucial and must complete their goals. This chart might be observed in Figure F.1, where the enumerated units manes are presented next to it, distributed into the observed 6 groups.

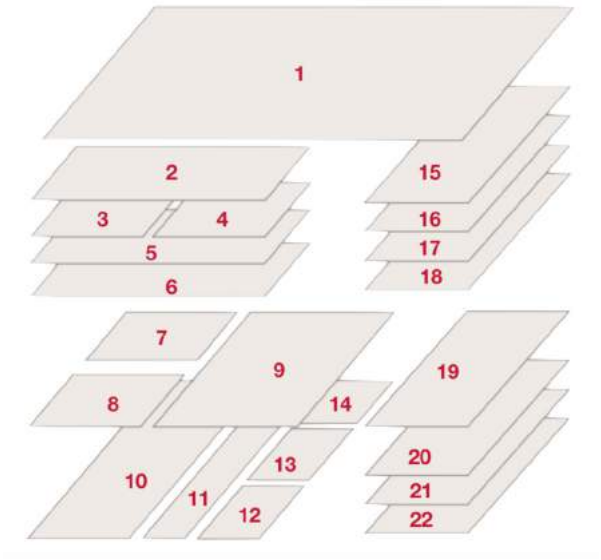

Figure F.1: Spire Global stack organization chart. Adapted from Spire Global Inc.

Regarding Figure F.1:

1. Customer.
2. Business, Marketing, Sales and Support (BMSS).
3. AIS Product.
4. GNSS-RO Product.
5. Data Services.
6. Satellite Operations.
7. Ground Stations.
8. Satellite Launch.
9. Command and Control Subsystem (CCS).
10. Manufacturing.
11. RF Quality.
12. Payload.
13. Satellite.
14. Communications.
15. Public Relationships and Brand.
16. Talent.
17. Office Management.
18. IT.
19. Legal
20. Finance.
21. Supply Chain.
22. Development Operations.

F.3.1 Coaches and Captains:

Instead of managers, the company has in each stack unit somebody in charge responsible of it and to keep data and communications flowing. These leaders are called Coaches and Captains, as explained in the previous section. They are the most important team members of the company.

- **Peter Platzer:** Co-founder and current CEO of Spire Global Inc., he was born in Austria, outside Vienna. He studied Physics at the Technical University of Vienna until 1996, and the following year started working as a strategy consultant at The Boston Consulting Group. During this time, he travelled through Europe and Asia making him discover new people and cultures. The company sent him to study a Master of Business Administration (MBA) at the Harvard Business School, which lead him to spend almost a decade on Wall street as a quantitative investment manager building models for emerging markets. in 2009 his life changed when he attended to NASA Ames for an eight-day executive program hosted by the Singularity University, where he was supposed to learn about broad trends driving global markets and left only thinking about space. This spurned him to study a M.Sc. in Space Science and Management at the International Space University, where he met his Nanosatisfi Co-founders. In April 2012 he founded the company and, once the separation of Ardusat from Spire Global occurred in 2014, he became a board member of the former. He is currently married to his co-worker Theresa Condor and live with their daughter nearby the Glasgow Spire Office [114] [124]. As CEO he is responsible in all the stack units.
- **Joel Sparks:** Co-founder and current CTO of Spire Global Inc. was born in Canada. He attended to the Carleton University for his Bachelor of Engineering in Aerospace Engineering with specialization in structures, systems and vehicle design. His studies continued with a M.Sc. in Space Science and Management at the International Space University, where he met the rest of Spire co-founders. He has worked at Mechatronic Systems as a Jr. Mechanical Designer, at Carleton University as a Research Assistant, at the Space Safety Magazine as News Editor and as an intern in Space Mechanism at EADS Astrium Germany. Since the foundation of Spire, he has been a Lead Engineer and is in charge of the Satellite Launch, CCS, Manufacturing, RF Quality, Payload, Satellite and Comms units. Currently working at the San Francisco office.
- **Jeroen Cappaert:** Co-founder and current CTO of Spire Global Inc. was born in Belgium. He Studied his B.Sc. and M.Sc. in Mechanical Engineering at the Catholic University of Leuven (KU Leuven). He performed his Master's Thesis with internship at the Von Karman Institute for Dynamics. Later he attended the International Space University for a M.Sc. in Space Engineering, Applications and Science, where he met the other co-founders of Spire. He had a short stay at the NASA Ames Research Center as CubeSat and Fluid mechanics researcher while the creation of Nanosatisfi. Since then, he is the co-CTO in charge of the Satellite Launch, CCS, Manufacturing, RF Quality, Payload, Satellite and Comms units. Currently working at the Glasgow office.
- **Theresa Condor:** Born in the USA, Theresa is the current Executive Vice President (EVP) of Corporate Development at Spire Global. With this, she is in charge of the BMSS unit. As the wife of Peter Platzer, she also lives with him and their daughter nearby the Glasgow Spire Office [114].
- **Alexander (Sandy) MacDonald:** Current Global Validation Model Leader and Director at Spire, he is in charge of the GNSS-RO Product unit.
- **Marcus Tallhamn:** Current Product Engineering Manager, he is in charge of the AIS Product, GNSS-RO Product, Data Services, CCS and Comms engineering units.
- **Austin Ellis:** Current Maritime Sales, Customer Experience and Satellite Operations Engineer at Spire, he is in charge of the Satellite Operations unit.
- **Jenny Barna:** Current Launch Manager at Spire, she is in charge of the Satellite Launch unit.
- **Daniel Bryce:** Current Manufacturing and Operations Manager, he is in charge of the CCS, Payload, Satellite and Comms units.

- **Nick Allain:** Current Director in Public Relations and Brand, he is in charge of the Public Relations and Brand unit.
- **Art Fischer:** Current Ground Stations Field Engineer and Business Operations and Facilities Manager, he is in charge of the Ground Stations and Office Management units.

F.3.2 **Employees Experience:**

The employees experience can be evaluated through the reviews they have posted in Glassdoor Inc. [121]. The posts date from September 22nd, 2014 to November 6th, 2018. The ratings and trends of these 18 employees' reviews show how 61% would recommend Spire to a friend and have a positive business outlook and 71% approve the company's CEO. The reviewers had to grade their experiences with the company in 5 different categories from 1 to 5. Those are the company's culture and values, the work/life balance, the senior management, the compensations and benefits and the career opportunities. The average rates for these categories stand at 4, 3.8, 3.5, 3.6 and 3.7. It is interesting to see how the rates have been somehow constant along time with exception of the work/life balance and the compensations and benefits that have increased its rates almost constantly. The Overall Spire Global Rating is calculated with a value of 4.

The reviewers also had to specify on the pros and cons of working at the company. Amongst the employees stated pros, the most repeated topics were their incredible experience working with satellites, the high qualification and motivation of the colleagues, the hard work, time and expectations the job involves and the reachability and closeness of the CEO. Some also mentioned that the offices present a relaxing familiar environment full of fun people. The company provides to each employee the possibility to work for a week a year in any of the other world offices with all the expenses covered, as well as a vacation policy of unlimited days. Spire Global also organizes different leisure activities and team building workshops that help the employees to get to know each other better. As ca curiosity, some reviewers have stated that Spire communicates each employee that they can name a company's satellite and provide free company lunches on Fridays.

The majority of the disagreements between reviewers come with the salaries, the personal and professional growth and reviews. For some, the first ones are competitive, but for others they are not. However, the general view is that the salaries are high for a start-up but not competitive for the sector.

The company does not have individual performance reviews. Instead a coaching system is implemented. Some employees see this as an advantage as the coaches help them develop personally and career wise. However, others see this as a drawback as the rewards system is not always awarded to the harder workers and the coaches seem not to be helpful for their employee goals.

Many issues with the coaches or managers have popped out in the reviews drawbacks. They have shown passive-aggressive attitudes telling employees something in one to one conversation but later forgetting it. Coaches have shown no coaching strategy or openness to suggestions. In addition, some employees have experienced situations in which a coach might suggest them to take a few days off with no consequence but when they come back, they can get fired with no notice.

Another repeated drawback is the logistic difficulty that having offices in many countries with different time zones implies, making employees to work during free time or holidays and making it hard for projects planning. Regarding organization, a few reviewers stated that the high levels of the company is more focused on the space program than in building a business.

Finally, one reviewer presented the most interesting drawbacks exposition. In addition to some of the ones already mentioned, this employee stated that the environment is extremely stressful, *dog eat dog* and cutting throat. The fear of being fired at any moment is present all the time, the co-worker's competition is fierce, and they will try to subvert others contributions and innovations. The *dog eat dog* environment is plausible with public email shaming and putting others down. Moreover, the reviewer points out that this is even stronger between women co-workers.

F.4 EO Market Segment & Requirements

Spire current products are based on the data collected by their Lemur-2 constellation (see section F.7). The company has an interest in markets defined in their 3 pillars: "*To collect data where nobody else can, to collect data not the size of the sensor but the number of sensors creating value, and to collect data where the sensors are programmable and re-programmable by software to really bring Moore's Law to space".* Those are where their CubeSats can collect data when no one else can, where the sensors number is more important than their size and where the sensors are in orbit reprogrammable, with the application of the Moore's law in space. This provides an always increasing customer value [125].

Nowadays, Spire Global operates in 4 defined market segments; advanced maritime domain awareness, critical weather data, air traffic data, and space-as-a-service (see section F.7). While the last one is special and based on the powerful Spire value chain, the first three are directly related to the collected data. Thus, Spire bring solutions with its products to 5 well identified sectors; Shipping and Maritime, Government and Military, Supply Chain and Logistics, Aviation and Meteorology [125].

F.4.1 Shipping and Maritime

Spire intends to help companies monitor their ships traveling through the oceans with its Sense product focused on the advanced maritime domain awareness market segment. They claim that the modern maritime transport involves many players with multiple roles as companies focused on owning and management of ships, shipbroking, chartering or market analysis. The data to analyse increases exponentially, and the combination of it can provide new insights. A good and quick understanding of the current and near-future market in combination with active change preparation can make companies survive and prosper. Spire helps them become data first and use diverse data sets so they can drive their best strategy.

The Sense product has improved and predictive AIS, the fusion of it with external data and a faster answer with better data delivery than other solutions (see section F.7). The Blue Economy market opportunity defines this solution. Some interested industries may be the Oil and Gas, the Fleet Management and the Financial Services [126].

F.4.2 Government and Military

Trustful and advantageous data is always sought by any public agency. A good use of data will define and lead the fore-coming decades. It also helps to cope with security and stability issues that can be harassed by illegal transactions, weather and climate disasters, among others.

Spire offers its AIS and ADS-B data to public institutions though the Sense and AirSafe products. This intends to help them deal with the illegal fishing, coast guarding and aircraft identification. Moreover, the Stratos product can provide meteorological, in-space TEC and ionospheric characteristics data. The last two sets are highly important for the military sector, as ionospheric space activity like solar flares can cause detrimental effects on GNSS and radio signals, blocking positioning information and reliable communications. Finally, Spire's space-as-a-service provides a reliable space platform for agencies to install their sensor payloads and gather customized data.

F.4.3 Supply Chain and Logistics

The Spire Global data sets help for many data-first supply chain and logistics firms to tackle high dimension problems and bring customers innovation. The data is collected from the GNSS, AIS and ADS-B payloads in the Stratos, Sense and AirSafe products. It is extremely useful as goods around the globe are composed by the ships and planes critical link. Nonetheless, the process starts away from shores and airports, where extreme weather can affect it. To illustrate the threats, natural disasters caused an economic loss of USD 211B only in 2016. In addition, more than 90% of the World trade is carried by sea, while about 33% of the US imports in value was carried by plane [127].

The combination of the maritime domain awareness, critical weather data, air traffic data with machine learning and AI platforms leads into better companies' decision making with increased transparency

and reduced risks. Spire's help can be seen even in route weather risks warnings that can be efficiently communicated, mitigated or solved [127]. This solution is highly related with the Blue Economy and Urban Development, Infrastructure and Transportation Management market opportunities.

F.4.4 **Aviation**

Spire helps aviation management optimization in safety, environmental conservation and profitability by identifying, tracking, and predicting aircraft movements. This has huge importance because there are more than 87,000 flights per day. The aviation sector generates big amounts of money in passengers and goods transport. Just in 2017 air cargo operations recorded USD 95.9B. Thus, preventing tragedies similar to the Air France flight 447 in 2009 and the Malaysian Airlines 370 in 2014 is a sector priority, as it is to Spire.

In combination with the new ICAO ADS-B regulations and the Lemur-2 constellation, Spire will be able to track any aircraft in the world with global coverage. Thus, Spire can provide airlines, aircrafts, airport operators and partners, the required ADS-B and weather data through their AirSafe and Stratos products. This helps them optimize their operational profitability and environmental efficiency of their aircraft operations.

F.4.5 **Meteorology**

With the threat of climate change and the increase of global business, weather and climate interest have raised. It daily affects each and every person over planet Earth. Spire offers global weather models that focuses on reliable forecast for people not living in Europe or the USA, where weather forecast is already good. They are also the only commercial GNSS-RO data provider, increasing forecast accuracy. In addition, Spire will provide GNSS-R data from late 2019, giving important data sets for forecasting (see section F.7 for more details).

Spire processes all these raw data to convert it into weather forecast through its cloud-based processing system. Thus, the Stratos product serves the customers this valuable information. The innovative practices by Spire has awarded them some NOAA contracts in demonstration projects for commercial meteorology. This solution is mostly related with the Environment and Climate Change market opportunity, even though it can form part of others.

F.5 Production System

A typical space data analytics value chain is formed by satellite design, satellite build and AIT, satellite launch, operations, data sales and analytics. Spire Global currently owns all the chain elements with exception of the satellite launch, which is subcontracted to selected partners (*NanoRacks, ISIS, ECM and RocketLabs*). Figure F.2 shows the aforementioned value chain and the Spire owned elements. This approach enables more control, speed and reliability, while the customer value provided, and the performance improvements raise at every iteration product update loop. In addition, the system cost usually decreases. In this way, Spire provides the highest quality data with the lowest possible risk [112].

Figure F.2: Space data analysis value chain and Spire Global elements ownership. Adapted from: [112]

F.5.1 Satellite Design

Spire bases its methodology in agile software ones, thinking about satellite iterations and engineering. Processes and ideas are kept only if they help the company achieve its goals. Thus, new things are welcome. The Spire satellite iteration model is an example, where major versions are used for backwards incompatible changes, minor for simple features and fixes, and branching to develop multiple features in parallel. This allows adaptability, satellite major improvement between iterations and different risk levels.

The design starts with a standard scope of work based on new feature ideas, customer request or needs. An initial mission level evaluation is held. In it, mission requirements and objectives are translated into a high-level satellite feature list, high-level trade-offs and a set of budgets to determine mission feasibility and overall scope of change of the CubeSats platform. With the results of the evaluation, the satellite design team performs a satellite deep-dive review. Its outputs are a system list of action, a subsystems detailed requirements list, and satellite and subsystems qualification plans [125].

In the following stage subsystems are designed and then reviewed with qualifications test reports. If no changes are needed, it is proceeded to the design flight hardware acquisition. All the documentation and required hardware and software tests are produced and carried out at this stage. The next stage sees the building of a qualification model, equivalent to a future flight model. It is used for satellite qualification plan integrated testing and will remain on Earth for future platform revisions. Once the tests are passed, a Certificate of Compliance (CoC) is created and signed by the satellite design and manufacturing teams, and the satellite operations mission director.

Finally, designs are given to the manufacturing team and the supply chain team starts acquiring hardware for the satellite building. A list of actions is also handed to the ground systems and satellite operations teams. Then the satellite can be put into production by the latter.

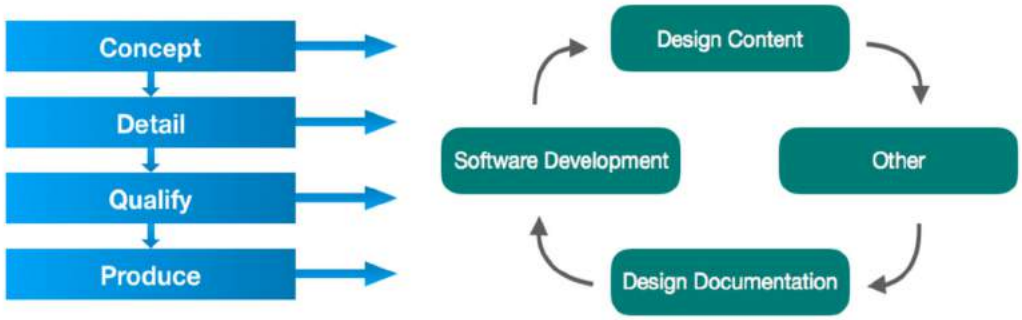

Figure F.3: Spire's satellite design process. Adapted from [125].

Spire's design process is not fully linear, as it contains many iterations and back and forth movements. Figure F.3 illustrates the process scheme. However, Spire has clear that the engineering team must deliver documentation as an output. They sustain that "*a brilliant idea is not useful if it can't be communicated*" [125].

F.5.2 Satellite Assembly and AIT

Spire developed an internal software that helps them store all the design data, supply chain and finance data, and manufacturing data together in the same place. It is also the documentation main channel and keeps all the already in orbit satellite data available at any point. The system then supports their fast iteration cycles, allows them to be lean and flexible in their engineering processes and ensures quality and reliability [125].

Another reason why Spire can afford fast iteration cycles is the ownership of a satellite Assembly, Integration and Testing (AIT) team and their associated systems and facilities. When a component is

received in the facilities it has to undergo incoming inspections and tests. They are almost fully automated to allow employees to focus on the results and not the procedures. After documented in the software, the components are back to the shelfs. They are only picked up when a satellite has to be assembled according to schedule. Once mounted, the CubeSats undergo integrated functional and environmental testing. Then, they are ready to launch.

The fact that Spire owns the building and tests facilities has brought many advantages. It increases their satellite build capacity and flexibility, reduces dramatically satellite test times and allows their engineering teams to perform more thorough root cause investigations, new feature qualifications and subsystem qualifications [125].

F.5.3 Ground Stations

Spire saw, since the beginning, the need to own the ground stations element in the value chain (Satellite Operations). This gives them flexibility to operate their constellations and acquire data. In addition, the ground stations network helps them optimize their constellation contact time. As there is only the need of compatibility guaranty with their constellations, the ground stations given costs are lower. However, Spire uses surge-support ground stations from partners (AWS Ground Station, Spaceflight Networks) if needed by the data requirements.

Spire owns more than 30 ground stations across all 7 continents of the Earth. This network combines UHF and S-band ground stations, with the intention to incorporate X-band capabilities to the network. They operate in bent-pipe mode, leaving no data unencrypted. The ground stations are designed, deployed, maintained and monitored by the spire ground stations team. They use a similar iterative approach to design the stations than the spacecraft team for the CubeSats [125].

F.6 Operations

Spire Global has launched 99 CubeSats by January 1, 2019. They can be classified in 4 different missions, with 2 of them still being active. The company is specially focused on their most successful project, the Lemur-2 constellation, with a new update of the satellites introduced in March 2018. Spire's operations are explained in this section, being categorized by past, present and future actions.

F.6.1 Past Operations

There have been 3 different satellites launched by Spire (or NanoSatisfi at the time) that are currently not operating. They are the ArduSats -1, -X and -2. The first two corresponded to the company's first mission, while the third one composed a different mission derived from the previous. Each of them had a different architecture and are explained below.

F.6.1.1 ArduSats-1 and -X

The ArduSat-1 and ArduSat-X are identical 1U CubeSats with the mission to provide an open source platform for students and space enthusiasts. They could design and try their space experiments based on the Arduino platform. As previously mentioned in section F.1, this project was successfully crowdfunded and deployed from the ISS by the Japanese JEM Small Satellite Orbital Deployer (J-SSOD) at 400 km above the Earth surface. As a typical 1U CubeSat, they have a weight of 1 kg and a dimension of 10 × 10 × 10 cm. Their primary downlink occurs in Ultra High Frequency (UHF) at 437 MHz.

Their main Payload/Processor is a bank of 16 Arduino processor nodes (ATmega328P) with 1 supervisor node (ATmega2561) that uploads the Arduino bootloader code from the experiments to each processor node. Then, they run them individually. The Ardusat-1 and -X obtain their power from solar cells and batteries. They have no propulsion.

The experimental code was developed using C or C++ language for AVR/Arduino using the Ardusat Sensor SDK software package. It was designed to facilitate the interaction between developers and the sensors of the Ardusat Space Kit in addition to providing an unified interface with the same interaction code [128].

The data sampled by the processors using the code may be obtained from the multiple payloads the ArduSat-1 and ArduSat-X have. More information about their payloads can be found in section F.7. Both Ardusats already re-entered the atmosphere on April 2014.

F.6.1.2 ArduSats-2

The Ardusat-2 is the developed improved version of the Ardusat-1 and -X. It is a 2kg 2U CubeSat that tries to approach the ISS science to everyone. That is achieved thanks to the implementation of off-the-shelf equipment into a satellite that would collect data in space. Thus, it tests hardware and electronics intended for Earth usage at LEO, aiming to lower its access costs.

The Ardusat-2 is very similar to its older versions (-1 and -X). It is based on the Arduino technology and was also a crowd-funded project. This CubeSat was intended for students and space enthusiasts to develop their own software. However, it has a complex more developed established chain of software that goes from the low-level assembly code controlling the sensors to the C/C++ code for the on-board software and the Ruby on Rails, SLQ or Python code for the ground and higher-levels architecture. The Ardusat-2 obtains its power from solar cells and batteries. It has no propulsion.

This satellite primary downlink occurs in Ultra High Frequency (UHF) at 400MHz while the secondary is in S-band at 2.4GHz. Similar to its older versions, the Ardusat-2 orbits at an altitude of 400 km with 51.6°, as a consequence of its ISS deployment (see section F.1). Its deployer was the NRCSD (Quad-M) by NanoRacks.

The sampled data is obtained by its multiple sensor payloads and processed by its Atmel chips microprocessor payload. More information about its payloads can be found in section F.7. The Ardusat-2 Already re-entered the atmosphere on July 1, 2014.

F.6.2 Current Operations

Nowadays there are dozens of operative Spire satellites in the space. They can be classified into 2 different missions, the Lemur-1 sole satellite and the Lemur-2 constellation. At the same time, the latter presents two subgroups of satellites, explained more in detail below.

F.6.2.1 Lemur-1

The Lemur-1 is a 3U CubeSat that serves as a prototype for a larger constellation of satellites. It is then a technology demonstrator of various science payloads, with the final intention to open meteorological, aeronautical and maritime potential commercial markets. It weighs about 4 kg and has an orbit with a perigee and apogee of 612 km 697 km respectively. The Lemur-1 primary downlink band is UHF at 402MHz. Its inclination is of 97.98° and its Period lasts 97.82min [129].

he fourth satellite from Spire (then Nanosatisfi), was launched on board of the Dnepr launch vehicle in 2014. Its launching site was the Yasniy site at the Dombarovsky Air Base in Russia. The deployment was done in orbit by the Italian UniSat 6 using a P-POD. The Lemur-1 obtains its power from solar cells and batteries. It has no propulsion.

The Lemur-1 carries 2 additional EO payloads. Information about them can be found in section F.7. This CubeSat is still operational.

F.6.2.2 Lemur-2

The Lemur-2 is the main satellite constellation by Spire. It is composed by 3U CubeSats with the same Lemur-2 name. The name Lemur stands for Low Earth Multi-Use Receiver, as for its predecessor Lemur-1. The CubeSats weight about 4.6kg, have no propulsion and are powered by a deployable solar cells array and batteries. Their dimensions are of 10 × 10 × 34.5 cm. The Lemur-2 primary downlink band is UHF at 402 MHz, while the secondary is S-band at 2.02 GHz. It is designed, built, and operated in-house by Spire. Figure 4.4 presents an image of a Lemur-2 CubeSat.

Their current objectives are to track maritime, aviation, and weather activity from space. The first one aims to solve the impossibility to track a ship traveling long distances because of the Earth’s curvature. The spaceship tracking would increase security and safety across the oceans. The second

one intends to operate similarly to the first but for the aviation sector. This will provide actual location data instead of currently used computer models for aircraft location prediction in remote zones. Last but not least, the third objective aims to provide weather data independently of the geolocation and altitude, with big interest in areas where no weather stations or balloons are available. More information about the Lemur-2 payloads used to accomplish these objectives can be found in section F.7.

There have been 95 Lemur-2 launched satellites, with 12 having re-entered the atmosphere after being operational and 10 having had a launch failure in November 28, 2017 by the Soyuz-2-1b Fregat-M launcher. The Lemur-2 13 Beccadewey experienced a deployment failure when it didn't deploy from the Cygnus OA-6 in June 22, 2016. Thus, by January 1, 2019 there are 72 operational Lemur-2 CubeSats. There have been 6 different Launch vehicles to bring these satellites to space; the PSLV, the Atlas-5(401), the Antares-230, the H-2B-304, the Soyuz-2-1b Fregat-M and the Electron Curie. Once launched to space, the Cubesats are deployed. There have been 5 different deployers used; the ECM 12U by ECM, the External-NRCSD and NRCSD by NanoRacks, the Maxwell deployer by RocketLabs and the QuadPack by ISIS.

The constellation Cubesats are spread along many LEO orbits, with altitudes from 400 km to 640 km and inclinations ranging from Equatorial to Sun-Synchronous Orbit (SSO). This results into an almost global coverage pattern with low latencies and high revisit times [125].

Figure F.4 Completed Spire Lemur-2 3U CubeSat. Image credit: Spire Global Inc. [130].

F.6.3 **Future Operations**

Spire intends to continue to increase and update the Lemur-2 constellation. There is no official number for the intended operational satellites of the constellation, but it is believed that it would be around 100. There are 51 new Lemur-2 Satellites expected to be launch in the following years, with 47 planned for 2019 and 4 for 2020. With a total number of 72 operational Lemur-2 Cubesats by January 1, 2019, one may think that this exceeds the 100 mark. However, new technologies and payloads are constantly updated in this Cubesats, while older Lemur-2 may become inoperative and obsolete [131]. As an example, only 17 Lemur-2 incorporate the ADS-B payload. This is not enough to maintain the global coverage. In addition, the new GNSS-R service will be available from the third quarter of 2019, requiring new processing and improvements of the GNSS receivers (see section F.7 for more information).

F.7 Satellite Payloads and Applications

This section summarizes the Payloads of the satellites presented in section F.6 and their applications in the form of products or services. As currently Spire only focuses on the Lemur-2 constellation its related topics will have greater importance.

F.7.1 **Payloads**

This section presents the different payloads that are or have been mounted in the different Spire Global Cubesats. For more information about the satellites and their operations consult section F.6.

F.7.1.1 ArduSats-1 and -X

The identical ArduSat-1 and Ardusat-X incorporated multiple sensor payloads in addition to the main Processors payload. By using the students developed code, the processors access the other sensor payloads and obtain the desired sampled data. A list of the ArduSat-1 and Ardusat-X sensor payloads is found in table F.1.

Table F.1: ArduSat-1 and ArduSat-X sensor payloads. Extracted from [132].

Sensor Payloads	
Payload	Description
Optical Camera (C439)	Single Complementary Metal-Oxide Semiconductor (CMOS) module built by SICUBE with 1.3MPx.
Optical Spectrometer (Spectruino)	Single device designed to work with Arduino in a wavelength range from 400 nm to 760 nm. Built by MySpectral.
Luminosity Sensor (TSL2561)	2 sensors covering IT and visible light to digital signals. Placed besides camera and spectrometer. Built by Adafruit Industries.
Geiger Counter (LND 716)	2 sensors that monitor the radiation environment of the satellite detecting gamma rays. Built by LND.
Digital Temperature Sensor (TMP102)	4 low power sensors with 0.5ºC accuracy. Used to track internal and external temperature. Built by Texas Instruments.
IR Temperature Sensor (MLX90614)	Single wide sensing range device with capability to measure Earth emissivity. Built by Melexis.
Accelerometer (ADXL345)	Single low power highly sensitive 3-axis digital device capable of tracking the satellite acceleration. Built by Analog Devices.
Gyroscope (ITG-3200)	Single 3-axis digital gyro. Compact, robust and sensitive device that senses satellite movements. Built by InvenSense.
Magnetometer (MAG3110)	Single digital, small and low powered 3-axis magnetometer which is able to measure the Earth’s magnetic field. Built by Freescale.

F.7.1.2 ArduSat-2

The Ardusat-2 incorporates similar payloads to the -1 and -X Ardusats. However, as it is an improved version, its payloads are too. The main premise to select the payloads was their Consumer-Off-The-Shelf (COTS) nature with space usage capability for specific or limited applications. Thus, the good Earth-rated technology is brought to the space with dramatically cheaper prices due to their Earth mass production.

The multiple common and complex sensor payloads are connected using and augmented Inter-Integrated Circuit (I2C) protocol. The common COTS sensors are magnetometers, accelerometers, gyros and temperature sensors. On the other hand, more complex sensors are the Geiger counters, a camera, a spectrometer and a VHF radio beacon receiver. Nonetheless, the latter group is still composed by off-the-shelf sensors.

A supervisor processor communicates with the multiple Atmel chips microprocessor payload through a proprietary communication protocol. As a consequence, the individual computational nodes of the payload are under very fine control. Most of the bus-components are standard spaceflight hardware. They have a Technology Readiness Level (TRL) between 8 and 9.

F.7.1.3 Lemur-1

The Lemur-1 incorporates diverse technology demonstration payloads. In addition, it also carries 2 EO payloads. They are an Electro-Optical and a low-resolution IR imaging system. The former is its primary EO payload and operates in the visible light band with an approximately 5m ground resolution. The latter is the secondary EO payload and has a ground resolution of approximately 1 km.

F.7.1.4 Lemur-2

The Lemur-2 constellation satellites have the objectives of weather monitoring, global maritime and aviation tracking. The payloads to achieve such missions are a GPS/GNSS receiver for GPS-RO/GNSS-RO, an AIS and an ADS-B receiver respectively. In addition, the Cubesats incorporate an Attitude Control and Determination System (ADCS), communications systems and possible customized, experimental or technology demonstrator payloads. However, not all the payloads are on board of all the constellation CubeSats. While all the Lemur-2 have the GPS-RO/GNSS-RO and AIS solutions, only the ones launched after May, 2018 incorporate the ADS-B payload [133].

F.7.1.4.1 GPS/GNSS receiver

Spire aims to reach global coverage on weather monitoring with consistency, reliability and cost effectiveness. The current weather satellites are generally diminishing due to technology obsolescence and resulting into inaccurate, unreliable and short-term meaningful weather forecast. a better option are the weather balloons and ground stations, but they lack the global coverage.

The Lemur-2 satellites incorporate GPS/GNSS receivers capable of Global Positioning System Radio Occultation (GPS-RO)/Global Navigation Satellite System Radio Occultation (GNSS-RO). This technique consists in the occultation of the geospatial satellite signals by a LEO satellite. These signals will have to travel through the atmosphere, suffering refraction and time delay, as observed in figure F.5. The angle of refraction depends on temperature and water vapor content. Thus, as the geospatial satellites pass through various atmosphere levels, relevant weather data is obtained. the data output provides profiles of bending angle, refractivity, and dry temperature as a function of altitude during a radio occultation event. The subsequent manipulation provides pressure, temperature, and humidity of the atmosphere profiles with high precision. The GNSS receivers can track the GPS, Galileo, GLONASS and QZSS geospatial satellite constellations [134].

In addition to the GNSS-RO capabilities, the GNSS receivers can help estimate the ionospheric Total Electron Content (TEC), calculates the ionospheric Scintillation Indices and from the third 2019 quarter will provide Global Navigation Satellite System Reflectometry (GNSS-R). The first one is computed in the post processing of each GNSS satellite signal by a linear combination of dual GNSS

frequency phase measurements. The Scintillation Indices indicate ionospheric turbulence in the upper atmosphere that could jeopardize GNSS receivers to provide robust and accurate position, navigation and timing and lead them to loss-of-lock. The indices are calculated with the measurement and combination of the scintillation amplitude and phase. Finally, the GNSS-R is a technique that uses GNSS signal transmission as passive bistatic radar signals to measure Earth surface properties. This measurement can estimate over sea surface its roughness, wind speed, heights and ice extent maps, while over land surface its soil moisture and flood inundation/wetlands extent maps [135].

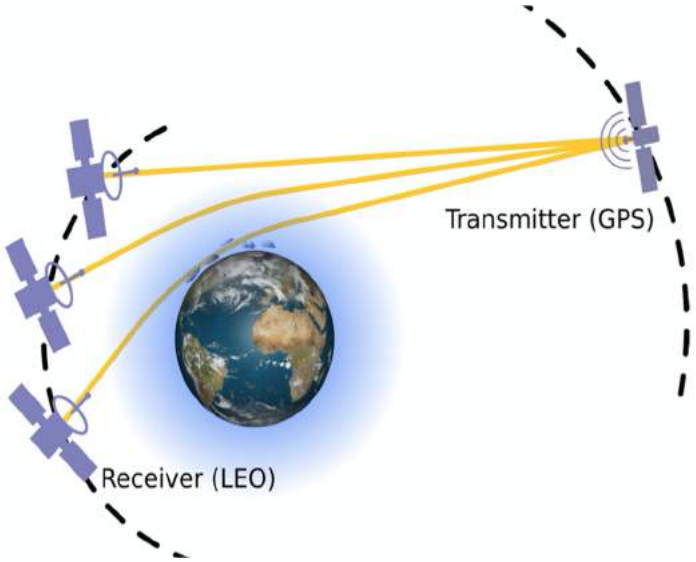

Figure F.5: GNSS-RO and GPS-RO diagram. Image credit: Earth Observation Data Centre for Water Resources Monitoring.[136]

F.7.1.4.2 AIS receiver

Maritime vessels tracking in deep ocean is impossible for land-based stations. The reason is that the Earth's curvature blocks the communication signals after their distance is greater than 50 NM. Maritime tracking is crucial for world's economy as more than 90% of global trade transits the oceans.

Each Lemur-2 incorporates an Automatic Identification System (AIS) receiver for ships at sea signals communication. This system has been mandatory in the maritime sector since 1974 and has been used by ships to communicate through VHF messages with identification, position, course and speed information. AIS permits vessel tracking, contributing to maritime safety, search and rescue operations, collision avoidance and maritime domain awareness. Satellite AIS as provided by Spire complements terrestrial AIS coverage by allowing enhanced world remote areas coverage, as shown in figure F.6. Thus, Satellite AIS primary advantage is global coverage while terrestrial AIS one is extremely low latency. Area examples are oceanic and Arctic regions [137].

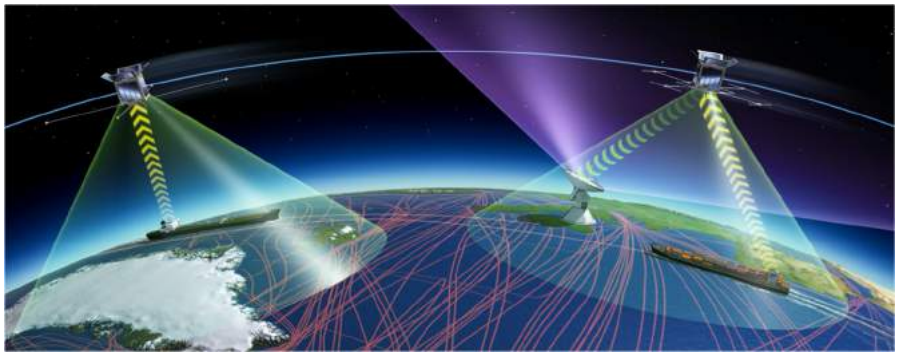

Figure F.6: AIS diagram of global ships linking. Image Credit: Artes-ESA [138].

F.7.1.4.3 ADS-B receiver

Similar to the maritime sector, aviation also presents a critical need for global flight tracking. Up to now, the tracking system was mostly land and radar based, with huge accepted gaps in coverage specially over open oceans and remote areas. New flight tracking and surveillance technology Automatic Dependent Surveillance-Broadcast (ADS-B) uses GPS signals to determine airspeed, location, heading and other information about aircraft. An ADS-B transponder in an aircraft sends signal beacons to other ADS-B receivers. They contain the aircraft essential information. The receivers were initially ground stations and other aircrafts. However, the land-based stations present issues with range and costs. The Line-Of-Sight (LOS) range of communication is typically about 150 NM without obstacles. On the other hand, a new terrestrial ground station can cost up to USD 12M in building and maintenance.

Space ADS-B solve range and costs issues of the ground stations. The emitted signals from the aircraft are captured in space by the receivers and then broadcasted to a ground station network. Then, all the aircrafts data is transferred to a cloud infrastructure network where aviation authorities and operators can access it. Figure F.7 graphically supports this explanation. Lemur-2 satellites launched after May 2018 incorporate ADS-B receivers, making a total of 18 Cubesats.

The use of terrestrial ground stations around crowded areas and satellite receivers around remote ones helps obtain the best from both worlds. The satellite stations improve situation awareness and lowers the infrastructure costs. Space-based ADS-B will present more security, reliability and better long-term savings [139].

F.7.1.4.4 ADCS Magnetometer

The Attitude Control and Determination System (ADCS) can continuously collect the Earth's magnetic field from the system's magnetometer, which is based on magneto-inductive technology. It gives high-performance resolution and repeatability with high sample rates, high gain, low hysteresis and no temperature calibration need. Its time resolution can be either 4 Hz or 0.1 Hz [140].

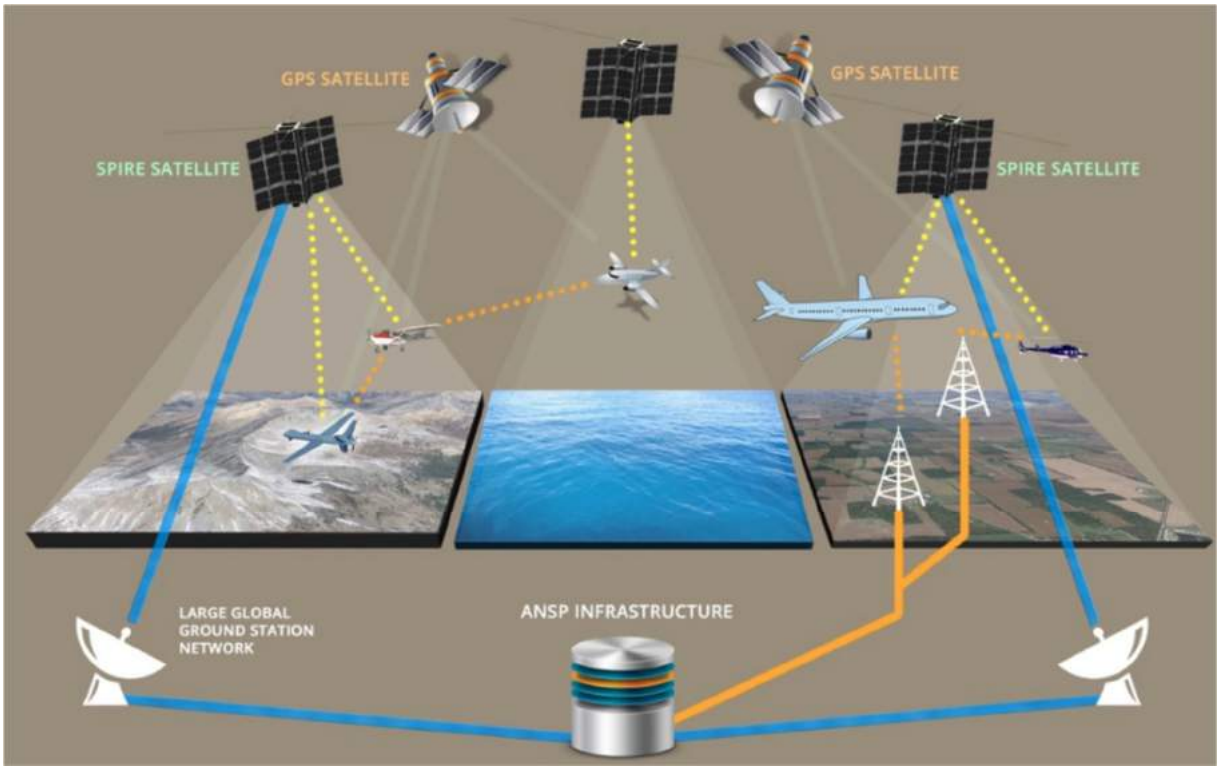

Figure F7: ADS-B signals diagram between aircrafts, satellites and ground stations. Image credit: Fernandez and Preston.

F.7.2 Applications and Products

Spire Global operates in 4 market segments; advanced maritime domain awareness, critical weather data, air traffic data, and space-as-a-service. The first 3 are defined as the Sense, Stratos and Airsafe products respectively. They are directly related to the Spire Lemur-2 constellation collected data. The last segment is leveraging all the Spire space data analytics value chain elements that have been built over the years. For a space company they consist of satellite design, satellite build and Assembly, Integration and Testing (AIT), satellite launch, operations, data sales and analytics. The only element Spire doesn't own is the satellite launch, which is operated by a selected external partner [125].

F.7.2.1 The Sense Product

The Sense product is based on the acquired data by the Lemur-2 AIS payload and is designed for full maritime awareness through ship tracking. The collected data is processed through cleaning, attachment to specific vessel identifiers, and combination with other vessel-specific information. This creates a global coverage database of ocean-going vessels that is enhanced by an Artificial Intelligence (AI) software. The database updates every 15 min, contains more than 400,000 ships, sees over 120,000 vessels per day and its AI software predicts vessels positions up to 8 h forward. The vessel data provided by Sense are the International Maritime Organization (IMO) and Maritime Mobile Service Identity (MMSI) identifiers, the vessel type and size, the commercial owner, the current and historic Lat/Long coordinates, draught, speed, heading and the ports of departure and destination [141]. Figure F.8 presents the global data gathered by the AIS and ADS-B payloads for the Sense and AirSafe products for 3 months. It shows the tracks of the monitored ships and aircrafts in blue and red respectively.

Figure F.8: Global AIS and ADS-B data after 3 months of operation. Image Credit: Spire Global Inc. [142].

Interested parties in acquiring this product might be mining companies, port operation facilities, ship traders, brokers and supply chain companies, financial trade companies, intelligent data platforms and security and surveillance companies or governments. The latter may be interested due to the Sense capability to support identification of transhipment, illegal movement of goods and illegal fishing [143].

Spire provides the Sense product through an Application Programming Interface (API) that empowers users to take advantage of the vessels acquired data. This API functions through a modern developer-enabled interface. It is able to handle route efficiency, emissions planning and raw commodity cargo estimation solutions with large scale. Spire offers 3 Sense monthly plans; base for USD 3,750 monthly, standard for USD 5,100 monthly and premium for USD 8,600 monthly. The first one is more suitable for a need of raw undecoded AIS data. The second one a third are similar, with both having extended high traffic zone coverage and online data display, in addition to the basic already-mentioned information. However, the premium plan includes a vessel property database, predict algorithms and a cargo database for the following year quarter [142].

F.7.2.2 The Stratos Product

Stratos is the Spire product based on the data acquired mostly by the GNSS receivers installed onboard the Lemur-2 Cubesats. It provides data from the earth's atmosphere, ground, oceans and magnetic field. Stratos provides the temperature, pressure, and moisture vertical soundings through the atmosphere from the GNSS-RO technique, the estimated ionospheric TEC, the ionospheric Scintillation Indices and the Earth's magnetic field from the satellites ADCS. Since the third quarter of 2019 Stratos will also provide customers estimations on roughness, wind speed and heights (altimetry) over sea surface, ice extent maps over oceanic regions and soil moisture and flood inundation/wetlands extent maps over land surface.

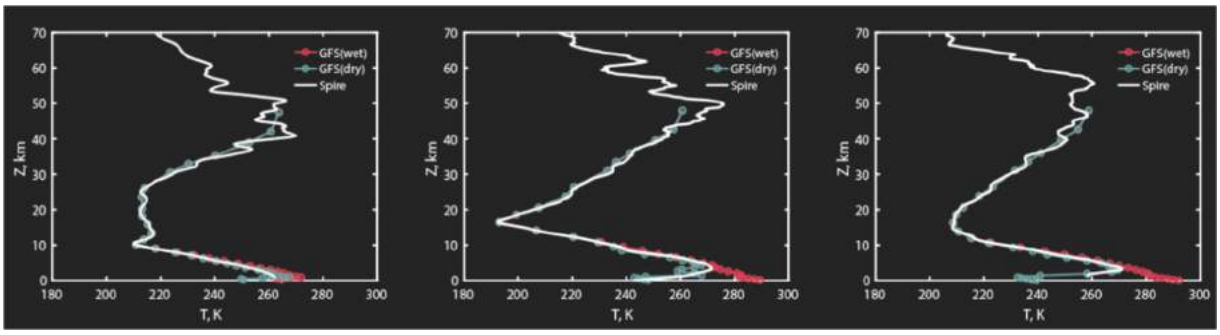

Figure F.9: Stratos profiles of temperature [K] against the altitude [km] for collected data, dry and wet GFS models. Image Credit: Spire Global Inc. [144].

The GNSS-RO data is output in a BUFR binary data format file containing the measured information. This format is used by the World Meteorological Organization (WMO). The available data includes Precise Orbit Determination (POD) files, LEO attitude files and the BUFR atmospheric retrievals. The POD process consists on the satellite position and velocity accurate tracking using GNSS. The GNSS-RO data has global coverage, a vertical resolution of 100 m and a temperature accuracy inferior than 1ºC.

The ionospheric TEC and scintillation indices have global coverage and 1 s time resolution. They are stored in podTec and scnLv1 NetCDF files respectively.

The future GNSS-R data set will be presented in NetCDF files. Its measurements will bring better spatial resolution and faster temporal repeat times than traditional point measurements. This is plausible in its spatial resolutions of 1 km over land and sea ice, and 20 km over open sea. The temporal resolution is of 1 s along the track sampling and continuous with sub-daily temporal repetition. The specific expected data includes surface normalized bistatic radar cross-section, the ocean mean square slope (L-band Limited), the sea surface wind speed, the sea ice extent maps, the surface reflectivity, the soil moisture and the flood inundation and wetland extent maps [144].

Stratos status and purchase method is unclear and Spire encourages customers to contact them personally for a believed product utilization.

F.7.2.3 The AirSafe product

The ADS-B payloads of the Lemur-2 satellite constellation acquire the data which is used for the AirSafe product. With commercial, military, business, and personal aircraft data being collected through ADS-B, Spire is developing the AirSafe platform. It will improve operations through increased air traffic visibility and replace ground stations in remote regions with better cost efficiency. Moreover, AirSafe will incorporate an optional weather data enhancement probably through a Spire's Stratos product data sharing.

The AirSafe service status is reported as having started early trials. The results from the downlinked data sampled indicates that the satellite performance was as expected or even better. Spire is currently persuading businesses to integrate AirSafe through personal private contact. This helps the company develop its technology and obtain test aircrafts while the clients are promised with more satellite launches and better AirSafe performance in the future. As an example, Spire announced a reselling partnership with the Japanese ITOCHU Corporation of the ADS-B data package in Japan and the rest of the Asia-Pacific region [144].

The global coverage AirSafe will provide an aircraft's full flight profile observation as well as some aircraft information. Figure F.8 shows the AirSafe aircraft flight profiles for data gathered during 3 months in 2018, along Sense data. The data contains the aircraft identification or ICAO address, the speed over ground, the vertical rate, the latitude, longitude and height coordinates, the barometric altitude, the GNSS height, the target state and the aircraft, operational, and emergency status [144].

F.7.2.4 Spire Orbital Services

Spire offers a space-as-a-service product focused on cooperation with business and governments. They intend to deploy co-created customizable data collection satellites in about six months. Leverages are instant due to Spire's almost monthly launching frequency. They also offer orbit flexibility, as the Lemur-2 are designed for LEO at any inclination. In order to acquire this service, a personal inquiry to the company is needed [145].

F.8 Online Platform

Spire Global owns the entire data chain. The sensed information is downlinked to the ground stations network located around the world (see section F.5). Automatized softwares help optimize the satellite-ground stations communications for best performance. The data is then processed through an analytics system and stored in the cloud depending on its type. Finally it is delivered to the customer [125].

The delivery of the data can be performed in different ways. On one hand, a customer could already have a visual layer to represent the acquired data. In this case, the product can be delivered in raw files (see section F.7.2). However, most of the companies will need a special tool to filter and organize the provided information. Spire then has partnered with companies such as Esci and MapLarge to provide data visualization tools and Geographic Information Systems (GIS). With them, customers can manage the amounts of data they want to interact with. GIS accepts inputs from different remote sensing techniques, selects the key data and organizes it into maps for analysis. Finally, if the Esri and MapLarge solutions are not suitable for the needs of a customer, Spire encourages to reach them out and explain more carefully their visualization needs. They intend to collaborate with the customer to find a visualization solution.

Spire provides access to customer developers to their Application Programming Interface (API). Through it, customers can access, modify and request actions in the Spire cloud data. So far, Spire has developed only the Messages and Vessels APIs from the Sense product. However, the remaining offered products' data is intended to be offered in a similar way. Thus, this API requests the data to the cloud, which can be delivered in many ways.

The visualization platforms that Esri and MapLarge offer are then a more sophisticated version of Spire's API. Their interface is more customer-friendly and the data can be seen in GIS global maps. However, it is basically an intermediary between Spire's API and the customer. As an example, the

setting of the Esci platform GeoEvent requires a first step of establishing a connection with the Spire's API. With it, features of the AIS messages and vessels are updated and their history is retained, creating a heat map of ships activity [146].

F.9 Partnerships

Partners for Spire are key in some areas of their value chain, as well as in their development. The only element of the chain that they don't own is the satellite launching, but other areas benefit from their partnerships with the most well-regarded and forward-thinking industry companies. This could be the case of the ground stations network or their products development. Moreover, Spire has sealed other partnerships with diverse intentions.

The ESA is of the most important partners Spire has. As a space agency, the ESA is a key partner for Spire's technology development. It was first reflected with the award of GBP 4M from the ARTES Pioneer programme, which funds the demonstration and validation of advance technologies in space in order to eventually commercialize it to the public or private sectors. With it, both parties intend to bring space-as-a-service to the world. After the successful launch of the first 2 pioneer satellites in November 2018, both teamed up again to permit Spire use data from the Galileo constellation. This deal is worth up to USD 2.7B over the next 25 years to Spire and is crucial for the Pioneer mission objective, the validation of using nanosats for space-based GNSS-RO [120].

The partnership Spire sealed with **ESRI** in 2018 is of great value, as the cooperation leads to the creation of powerful and effective GIS products. Spire will help develop and support the ArcGIS platform and the datasets obtained from the LEO CubeSats is easily integrated into the platform. So far, this partnership is focused on the maritime industry, but may widen to the rest of Spire's datasets.

F.9.1 **Satellite Launching**

The versatility and size of the Spire's Lemur-2 Cubesats permits them to be launched and deployed from very different systems. Thus, many partner companies have been involved in this task depending on the intended satellite altitude and orbit. Spire closes a deal with a deployer company, which at the same time negotiates the rocket launching with a third-party launching company. Among the deployer companies one can find **ISIS, ECM, RocketLabs** or **NanoRacks.** The fact that Spire doesn't stick to a sole company for their satellite launching and deployment is due to the still constrained launch environment. Thus, smallsats operators should be flexible on their ways to bring their satellites to space, keeping and agnostic and opportunistic profile in front of launch providers.

As an example, the company signed a contract with **NanoRacks** to deploy 4 of their Lemur-2 Cubesats in March 30th, 2019, including Spire's 100th satellite. This company was selected as the first Spire's satellite was launched with them, and since then, up to 37 have done so. For NanoRacks, this was the first launch on board of the Indina PSLV rocket and represented the first customer contract between the India Space Research Organization and a small satellite rideshare company. The 37 previous satellite deployments via NanoRacks were performed from both the International Space Station and the Cygnus Spacecraft. Thus, new deployers needed to be manufactured, leading to NanoRacks to cooperate with Astrofein [147].

F.9.2 Ground Stations

Spire owns a Ground Station network of over 30 stations (see section F.5.3). However, Spire teamed up with **Amazon Web Services, Inc.** to use their new AWS Ground Station service, which will construct 12 ground stations by mid-2019 with a pay-per-use basis. This augments Spire's global ground station network and offers them faster speeds at lower costs. Spire's needs of downlinking data may vary depending on many factors. With the AWS Ground Station service Spire can instantly extend or overlap coverage on demand without any additional hardware expenses. Eventually, with AWS ground stations number being increased, Spire could remove the heavy costs of building and maintaining a ground station network and rent their capacity as the needs require [148].

On a different end, Spire's ground station network also has been commercialized for other companies. This was the case of the partnership with Spaceflight Networks in 2015. Spire offered ground communication services to the cost-effective satellite communications and data services company to expand global communications [149].

F.9.3 Products Development

Many companies have inked contracts of partnership in order to help develop their products. Spire's most advanced product is Sense, while Stratos and AirSafe still remain in early stages. The cooperation usually occurs at the point of analysing or presenting the data acquired by the Lemur satellites.

The Sense product is based on the AIS technology to track vessels around the world (see section F.7.2). In addition to the already-explained partnership with Ball Aerospace and the NGA to improve maritime traffic in the arctic, Spire has sealed other Sense partnerships:

- **ICEYE** teamed up with Spire to enable global monitoring of dark vessels and combat illegal fishing and transhipment at sea [150].
- **CSST** also partnered with Spire to provide Spire's AIS technology throughout the South Pacific Ocean. It will improve maritime situational awareness. Potential users could be the New Zealand government, military and port authorities.
- Together with **AXSMarine** enhanced maritime intelligence services are provided in the form of predictive and historical vessels data as well as their ownership [151].

The AirSafe product is based on the ADS-B technology to track and communicate with aircrafts around the world (see section F.7.2). In addition to the **INDMEX** and **Airbus** partnerships, Spire is working with **GE Aviation, Inmarsat** and **MapLarge** to bring flight analytics and global weather updates to the flight deck. This would integrate GE Flight Data Analytics with Spire's precise weather and ADS-B data on a MapLarge platform.

The most interesting Spire's partnership related to the Stratos product is with the NOAA. As already explained, this cooperation started in 2016 and, even though it didn't end up as desired, both parties re-joined in 2018 under a new contract.

F.10 Financial Status and Risks

Spire Global is a privately held company that started hitting up backers on Kickstarter in 2012. Institutional investments followed to later raise Series A, B and C rounds. The different investments are presented in table F.2. Up to date, Spire has raised about USD 140M in different funding rounds through 7 years. However, due to Spire's private company nature, it is illegal to clarify whether the company plans another round of funding.

It is interesting to observe that the June 2015 grant from the Scottish Enterprise happened at the same time as Spire opened its third global office in Glasgow. Something similar happened in November 2017, when Spire announced the opening of their fifth world office in Luxembourg together with a Series C funding round. This funding was led by The Luxembourg Future Fund. It is clear that these fundings rewarded Spire's new offices openings in their respective regions [115].

Spire's balance sheet can only be disclosed partially. Again, this is a direct consequence of the company being private. Thus, online sites such as *crunchbase.com* and *owler.com* estimate Spire's annual revenue in USD 2M [152]. However, Spire's co-founder and CEO Peter Platzer explained to journalist Elizabeth Howell in *Forbes* that their *"revenues are well into the eight-figure range and growing year-over-year in triple digits"*.

F.10.1 Spire Global Risks

Many financial risks may appear in a New Space company like Spire. Those include credit, interest, foreign currency exchange and liquidity risks. Due to the private nature of Spire Global, the information on how the company mitigates these risks is unavailable. However, the description and possible impacts of them can be presented:

- The **credit risk** is described as when a third party doesn't meet its financial obligations under a contract, leading to a financial loss. Spire could be vulnerable to this risk with different partners such as CSST, the NOAA, the ESA, ITOCHU and other interested parties in its Space-as-a-service offerings.
- The **interest risk** arises when the company takes a loan. No information is known about it, but a good monitoring of the interests may lead to limited effects on the yearly resulting finances.
- The **foreign currency exchange risk** appears as the company operates worldwide. Spire's sales costs and expenses may be primarily in USD, EUR, GBP and SGD due to their main offices locations. Thus, changes in foreign exchange rates may be significant for the finances of the company.
- The **liquidity risk** regards the lack of funding and adequate financial liquidity to meet short term financial demands. Liquidity is important in order to develop and expand the business. Good management and monitoring of funding as well as constant maintenance of cash assets will reduce the liquidity risk and allow payment capacity.

Table F.2: Spire's investment funding rounds data.

Funding Rounds				
Date	Round	Amount ($)	Lead Investor	Number of Investors
Jul. 2012	Crowdfunding	106K	-	-
Feb. 2013	Seed	1.2M	-	4
Jul. 2013	Seed	300K	Grishin Robotics	1
Jul. 2013	Seed	250K	Empiricus Capita	1
Oct. 2013	Seed	750K	Empiricus Capita	1
Jul. 2014	Series A	25M	RRE Ventures	5
Jun. 2015	Grant	2.9M	Scottish Enterprise	1
Jun. 2015	Series B	40M	Promus Ventures	5
Nov. 2017	Series C	70M	The Luxembourg Future Land	3

The company also has to manage other risks that may be or may not be related to the company, but would affect Spire's business, financial position and future results. Here are the most tangible risks [153]:

- The **execution risk** is tangible in Spire due to the production industrialization that the company has started. The increase of production volume comes inherently with a risk of underperformance. The company has so far succeeded in the production ramp-up and seems to keep growing with its different offices and working places.
- The **launch of the satellites** could constrain Spire's ambitious constellation. As the only value chain element not owned by Spire, the company is more vulnerable to third parties. Costs and availability could cause a reduction in their CubeSats launchings and eventually economic repercussions. Moreover, launching or deployment malfunctions are present factors with high probability that could lead to satellite losses, carrying bad consequences.
- The **market competition** inside the small satellites sector may threat Spire's market share. Competitors are also developing in terms of technology and products and a failure in cutting edge solutions may lead to a loss of offers and maker share. The increasing demand on LEO based services has increased the number of competitors, which may result on high competition on price and quality.
- Closely related to the previous risk, this **new and emerging market** could see competition from other developing sectors that may threat the smallsats market. The value proposition and technology development of other sectors like the large satellites, the terrestrial and the airborne platforms could stagnate or even eliminate the nanosatellites market. Spire may have to compete with on other fields such as price.
- The company's **customers** could also generate a risk if there are not enough or only few contact Spire's services. Thus, payments loses could lead to financial instabilities. However, Spire seems to have a good market share of customers.
- Retaining customers and obtaining more can be closely related to the **quality of the products**. A bad development of Spire's products or a lack of service quality may lead to inability to meet market expectations and an eventual adverse company impact.
- **Key personnel** are essential in a technology company like Spire. If the company is not able to retain or replace skilled personnel, ongoing projects and development plans may be interrupted with negative consequences for Spire.

Appendix G: Case Study - GomSpace

This appendix will present the Case Study of GomSpace. With the parent company now being GomSpace Group AB, it provides turn-key solutions for space-based business, developing and commercializing off-the-shelf payloads and platforms in the nanosatellites sector. Based in advanced radio technology, GomSpace solutions include Internet of Things (IoT), communications, tracking, surveillance, and remote sensing. This chapter is divided into History and Overview of the company (section G.1), Business Statement and Philosophy (section G.2), Ownership and Employees (section G.3), EO Market Segment and Requirements (section G.4), Satellite Payloads and Subsystems (section G.5), Platforms and Services (section G.6), Production System (section G.7), Operations (section G.8), Most important Partnerships (section G.9) and Financial Status and Risks (section G.10).

G.1 History and Company Overview

GomSpace was founded on January 1, 2007 in Aalborg, Denmark by a group of 3 entrepreneurs; Lars Alminde, Karl Kaas Laursen and Morten Bisgaard. They were Ph.D. students at the Aalborg University. Their experience gained doing research and development at the university based the foundation of the company. Before the creation of the company, these entrepreneurs worked in different CubeSat projects, such as the European AAU-CubeSat, the AAUSAT-II, SSETI-Express and Baumanetz projects. The name of the company was gestated during their student years. Then, they were known as the *"Grumpy Old Men"*(GOM) in academic circles as a consequence of their critical, enthusiastic and analytical approach to technology. The entrepreneurial spirit and their dream to *"put something into space"* drove them to become the world's first initiative takers for Nanosatellite missions [154].

Commercial from the start, GomSpace was established as an internationally recognized provider of Nanosatellites, subsystems and adjacent services. Its headquarters were located at the Novi Science Park. NOVI Innovation A/S partially owned GomSpace. The first projects were carried out focusing on research with customers in the academic and science sectors. In 2008 the first hardware products were delivered to customers. The development of the company kept parallel to the CubeSats sector. By 2010 GomSpace started to investigate in air traffic monitoring capability and in 2011 they delivered their first integrated Nanosat platform [155].

The greatest milestone achieved in 2013 is the launch of GomSpace's first satellite, the GOMX-1. This experimental 2U CubeSat was developed by GomSpace in collaboration with DSE Airport Solutions of Aalborg, and the Aalborg University. Its primary mission objective was to demonstrate in space air traffic monitoring using its main payload, an ADS-B receiver based on Software Defined Radio (SDR). Secondary missions consist on qualification of other subsystems such as a NanoCam C1U colour camera for EO and system software. It successfully validated the feasibility of space-based air traffic monitoring. At this point the company had 10 employees working for customers located in 30 countries [155].

The rapid growth of the Nanosatellite sector and its increasing commercial opportunities become the reasons behind GomSpace strategy shift in 2014. The company leaved its start-up phase and entered a growth phase with a new business focus. A renewed long-term vision embraced industrialization, aimed consolidation of the company and set the foundations for future large-scale Nanosats production. Regarding this expansion, an experienced CEO, board member and chairman of several companies, Niels Buus, was designated as managing director. However, this year also saw how the company second satellite mission couldn't get in orbit due to a launch failure of the cargo vehicle. The GOMX-2 2U CubeSat primary mission was to evaluate components in space such as optical communications, new generation SDR and a high-speed transceiver.

However, in 2015 their third Nanosat was successfully launched. The GOMX-3 3U Cubesat was a collaborative mission with the ESA that began in 2014 and exceeded all expectations at its re-entry in 2016. Its objective was to demonstrate advanced capabilities and performance of 2nd generation ADS-B signal reception and geostationary telecommunication satellite spot beam signal quality

through a reconfigurable SDR receiver. In addition, a third-party payload was flown in a miniaturized high data rate X-band transmitter from Syrlinks [156]. GomSpace reached the yearly 1000 CubeSats subsystems delivered mark for the first time in 2015 [157].

2016 was a key year for the development of GomSpace. On June 16 the company was listed at Nasdaq First North Premier in Stockholm founding GomSpace Sweden. This provided GomSpace with additional capital and strengthened its position in the sector. They also initiated projects based on their expertise. It is reflected in the agreement with the Danish Defence to deliver satellites for ships and airplanes traffic surveillance in the arctic, and the collaboration with Aerial & Maritime Ltd. (A&M) to provide satellites with the same purpose for near equatorial surveillance, emphasizing in Africa. In the same line, GomSpace agreed to provide radio platforms and antennas for the HawkEye 360 Pathfinder mission. Finally, the delivery of a full CubeSat platform was done to AISTECH. This company plans to set up a CubeSat network of 25 satellites capable of asset tracking and bidirectional communication, thermal imaging from space, aviation tracking and position management. It should be fully operative by 2020.

The Initial Public Offering came with positive growth consequences. The group acquired NanoSpace AB, completing their portfolio with satellite propulsion systems. The acquisition from the Swedish Space Corporation strengthened GomSpace market position in Sweden as well as adds participation in projects funded by the ESA. With the goal of facilitating access to launch services for the group customers, GomSpace opened a new subsidiary in Denmark, GomSpace Orbital ApS. This movement was done expecting contribution on a long-term basis. The group also increased the ownership of the subsidiary A&M to 47.3% based on the turn-key contract of CubeSats at low-inclination Equatorial orbit. GomSpace would design, deliver, launch and commission the constellation of Nanosats. By the end of the year, GomSpace Sweden AB counted with 77 employees, 43 more than in 2015 (30) and 61 more than in 2014 (16) [158].

The year 2017 was sweet for the GomSpace group. After restructuring in 2016, the company's growth turned out to be higher than planned. Thus, the number of employees raised up to 176, 99 more than the previous year. Among them, the management team acquired experienced people in similar positions to handle the growth challenge. The new board of directors impulsed the parent company change of name from ”GS Sweden AB” to ”GomSpace Group AB”. 3 new subsidiary offices were opened around the world; in Singapore, USA and Luxembourg. The first two will help operate the company's activities in their respective continent markets though GomSpace ASIA Pte Ltd and GomSpace North America LLC. The third one, GomSpace Luxembourg S.A.R.L., comes as a partnership with the Luxembourgian government to operate satellite constellations, data processing and distribution offered as a service. The office must count with 50 workers by 2021.

GomSpace headquarters also experienced an update with the new office spaces on Langagervej in Aalborg, Denmark, covering about 6,500m. The intention behind it is to develop a new production area capable of manufacturing *”one satellite a day”*. Regarding the company's accelerated expansion, GomSpace issued 1.75M shares in order to strengthen the company's financial position in a short timeframe. Directed to a selection of Swedish and international institutional investors, the private placement resulted at SEK 95M. In addition to this, another economic injection arrived in the form of a grant by the Innovation Fund Denmark. The DKK 2.5M contract aims to develop a large constellation management system and new radio components to improve broadband constellation communication [158].

Nonetheless, other major events occurred to GomSpace in 2017. The most important happening in February, when the company sealed a procurement agreement with Sky and Space Global (UK) Ltd. to develop and deliver a constellation of 200 satellites. With the first satellite intended to be delivered in 2018, the 4-year-period delivery agreement is valued between EUR 35M and EUR 55M. A similar agreement occurred with already-customers AISTECH. GomSpace agreed to supply up to 100 CubeSats for their constellation. The framework agreement was valued up to EUR 12.5M [159].

Related to the office opening in Singapore, GomSpace also signed a Memorandum of Understanding (MoU) with the Civil Aviation Authority of Singapore (CAAS) and Singapore Technologies Electronics.

It aims to explore the application and deployment of space-based VHF communications in the Singapore region for air traffic management. GomSpace associated company A&M obtained an investment of USD 5M to work in their CubeSats constellation. The consequences of the investment include the expansion of the constellation to 8 Nanosats, a solid foundation that will accelerate the development of the company and the reduction of GomSpace ownership share in this spin-off company from 47% to 39% [158].

At the beginning of 2018, a constellation of 2 6U Cubesats was launched, the GOMX-4. The project included the Technical University of Denmark, the Danish Defence and ESA. Its main purpose was to demonstrate satellite communication between CubeSats using Inter-Satellite Link (ISL). The two satellites shared the operational components and primary ISL payload but differed in their secondary payloads. The GOMX-4A incorporates ADS-B, AIS and imagery payloads. On the other hand, the GOMX-4B is equipped with a propulsion module, a Chimera board, an Hyperspectral camera and a star tracker [160].

During the year, many In Orbit Demonstration (IOD) projects were started, showing a favourable development of the company and the sector. But more specific contracts were signed. The ESA signed a EUR 1.575M contract with GomSpace to develop the Mega-Constellations Operations Platform (MCOP) at the Luxemburg's office. It aims to offer constellation operations services for small satellites. The close partner and client AISTECH entered a contract to acquire 6 CubeSat platforms for EUR 1.4M under the framework agreement previously signed. Kleos Space agreed on a contract with GomSpace that will provide them with a CubeSat constellation for an approximated value of EUR 4.42M. Finally, A&M inked a MoU to develop a satellite constellation and ground network worth USD 100M [158].

Regarding the success of the company, GomSpace revised its long-term targets during 2018. This included targets for sales over SEK 1.5B in 2023 and gross margin above 50% in the medium term. Moreover, the growing market in which the company operates makes GomSpace to continue prioritizing growth, meaning that shareholders should not expect dividends in the short to medium term.

Financial capital was also captured through 2 new issues of shares. In March an accelerated book-building procedure was carried out to finance and facilitate accelerated expansion. The issue provided SEK 125M and was intended to Swedish and international institutional investors. The second issue occurred at the end of the year. This preferential rights issue was subscribed for by 84.5% and GomSpace received about SEK 251M in proceeds amounting before transaction costs. This almost doubled the company's capital and number of shares, resulting in about SEK 3.66M and 52.27 M respectively [158].

The year 2018 also brought an important downturn. Sky and Space Global missed the payments of overdue invoices at SEK 33.317M related to the Critical Design Review (SEK 20.55M) and the payment for Batch 1 (SEK 12.766M). Working capital was negatively affected with a relatively low gross margin of 25%. The project was scaled down to minimums and later put on hold. This led to overcapacity and therefore re-direction of resources to other projects as well as non-revenue generating activities. The low capacity utilization resulted into reductions in staff at the end of 2018. After the reduction, the number of employees was recorded at 231, still 32 more than a year before [158].

2019 started with the announcement of a new payment plan for Sky and Space Global after the analysis of their cash flow situation. It was found that they would be able to solve their economic situation. The payment would be eventually received by March 2019 (SEK 20.55M). During the first quarter of 2019 GomSpace signed a contract with the ESA to join the advanced Nanosatellite HERA mission as well as a MoU with 2Operate to boost constellation management with AI. The first one will see GomSpace develop a 6U CubeSat for scientific tasks and eventually landing on the Didymoon asteroid, named Juventas. It will be the first deep space CubeSat developed by GomSpace. The MoU with 2Operate seeks to evaluate terrestrial telecom standards and existing AI solutions in future

satellite constellations in a robust and efficient way. This strengthens both companies collaboration regarding the MCOP project at the Luxembourg office [158].

The second quarter of 2019 saw GomSpace update its relationship with Sky and Space Global. It started with a Heads of Agreement for a new agreement that would revise and eventually replace the original Pearls agreement from 2017. A second agreement was also signed. It states the delivery of 6U CubeSats by GomSpace. The first batch of 8 satellites will be delivered by the first quarter of 2020 and has an order value of EUR 5.3M. An optional second 8 satellites batch could be delivered during the first half of 2020 and is valued in EUR 3.8M.

During this period GomSpace also partnered with TESAT and KSAT to develop full optical communications capabilities in small satellite missions and space-based services. However, it wasn't their only significant event, as they also signed 2 important contracts with ESA. The first one intends to adapt and improve SmallSat subsystems for deep space science missions and is valued in EUR 3.9M over 18 months. The second one is a Phase A design of the Miniaturized Asteroid Remote Geophysical Observer (M-ARGO) mission, which aims to develop the first ever CubeSat to rendezvous with an asteroid and perform close proximity operations for identification of in-situ resources. GomSpace will be in charge of the preliminary design of the mission, the 12U CubeSat spacecraft design and the implementation planning [158].

G.2 Company Business Statement and Philosophy

The mission of GomSpace is defined as "We help teams across the globe achieve their goals in space". This mission is supported by the company's vision; "To make Nanosatellites the preferred choice for customers who have demands for professional mission critical radio-based surveillance and communications solutions". In order to achieve that, the company defines its core strategy by being an "Independent horizontal supplier of technology for commercial service providers and government, education and research institutions – and spin-out activities in new untouched domains" [158].

The company has defined key growth phases to follow along the years. It can be observed in figure G.1. The first one, the Current phase, is characterized by the building up of the company through investments in product development and facilities. The second one, the IOD phase, is characterized by a high degree of non-recurring engineering. Finally, the Constellation phase is based on the materialization of the IOD projects with high volume production. This will lead to new IOD projects. GomSpace is nowadays transitioning between the Current and the IOD phases. Investments are still focused on the development of products and facilities, but the company already works on 4 IOD projects and is bidding on another 10. These 2 phases, the Current and the IOD, form the basis of the company's long-term goal of sales above SEK 1.5B by 2023 and the medium-term target of a gross margin over 50% [158].

GomSpace offers in its portfolio two kind of products, components and subsystems as a sub-supplier to other satellite manufacturers/operators or complete satellites or platforms called satellite solutions. The services and engineering involved in these projects also provide revenues.

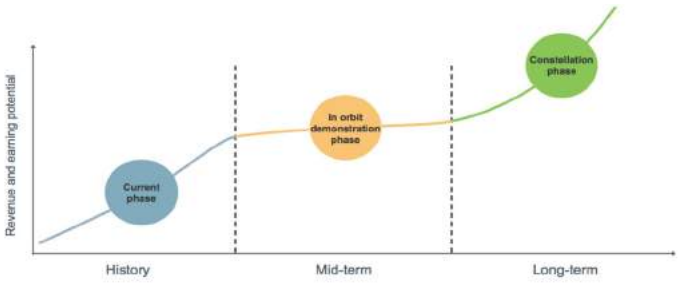

Figure G.1: GomSpace Group AB key growth phases to follow along the years. Image Credit: GomSpace Group AB [158].

However, some are not yet available. They are viewed by the company in their business model as constellation management services and additional services. GomSpace can achieve profitability over time from this engineering effort as it could be re-used in similar projects. Thus, the company's movement towards the market's lead can be determinant to scale the business faster. Nonetheless, the trend GomSpace is showing indicates that they are not interested in becoming a large-scale component supplier to competing satellite manufacturers but aims to be a full-service provider. That would include the satellites and adjacent services, launching services and constellation management. This trend is corroborated with the sales of 2017 and 2018. The first year showed that the sales were 65% of complete satellites and 35% of components. In 2018 the percentages varied to almost 80% and 20% respectively [158].

The strategy carried out by GomSpace can be summed up as *"aggressively build out capacity in order to scale the business and be ready for the increase in demand when it comes" [161].* Its competitors have used less risky strategies growing with profitability, but their chances of keeping the pace of the rapid growing marked are much lower. GomSpace has secured a high market share with 32% announced planned CubeSats launches in 2019 and 42% in 2020. Thus, the strategy GomSpace has adopted seems to be working [161].

The company's ambitious growth led them to develop a parallel strategy to enter different markets. It is based on the continuously extended potential areas of applications that the Nanosatellites have. GomSpace is establishing commercial satellite operators in subsidiaries together with joint-venture partners. The joint-venture companies aim to spin off while still using GomSpace resources. The main goal of GomSpace is to open up new areas of application that would require their products, hence increasing demand. GomSpace has significant added value in its current joint venture with Aerial & Maritime Ltd. and its ADS-B monitoring system constellation for tracking of aircrafts and predicting flight paths. Nonetheless, other potential joint-venture partners could be found in the Singapore Technologies Electronics, even though their relation could be of a supplier [161].

GomSpace success is based on some strengths, focus and market fundamentals [158].

- The focus on radio technology related missions with scalability to satellite constellations.
- The ability to seal major contracts with leading constellation customers like Sky and Space global, AISTECH or A&M.
- GomSpace investments made to increase activities in growth markets like the US and Singapore. Their market shares represent a 52% and 15% of the Nanosatellite market.
- The continuous investment in new technologies, through IOD and new applications, as well as new machinery for product industrialization.
- The building of the Luxembourg based service for operations and constellation management (MCOP).
- The positive outlook the space industry shows to Nanosatellite manufacturers, which respond with improved performance.
- A rapidly growing market, where the launches keep increasing.

G.3 Ownership and Employees

The holding company GomSpace Group AB has many operating subsidiaries and is listed on Nasdaq First North Premier in Stockholm, where the registered office is located. Those subsidiaries can be observed in figure G.2 and are listed below [158].

- **GomSpace A/S:** Being the core subsidiary of the group, GomSpace A/S is located at the headquarters of the company in Denmark. It copes with the design, integration and manufacturing of the high-end CubeSats component parts and complete solutions. The launch services facilitator subsidiary, GomSpace Orbital ApS, can be considered as part of GomSpace A/S.
- **GomSpace Sweden AB:** Formerly known as NanoSpace AB, this Swedish subsidiary develops and provides propulsion technology and products for Nanosatellites. It is involved in many ESA projects. Hosts a propulsion technology centre in Uppsala.
- **GomSpace ASIA Pte Ltd:** Located in Singapore, this sales & project development subsidiary spearheads the company's growing operations around Singapore and the entire Asia.
- **GomSpace North America LLC:** With its office in Washington DC, this sales & project development subsidiary plays a big role in the attention catching of the US and American continent markets. They operate all activities in America.
- **GomSpace Luxembourg S.A.R.L.:** Being located in Luxembourg, this subsidiary aims to develop an operations centre as a service for constellation management of Nanosatellites.

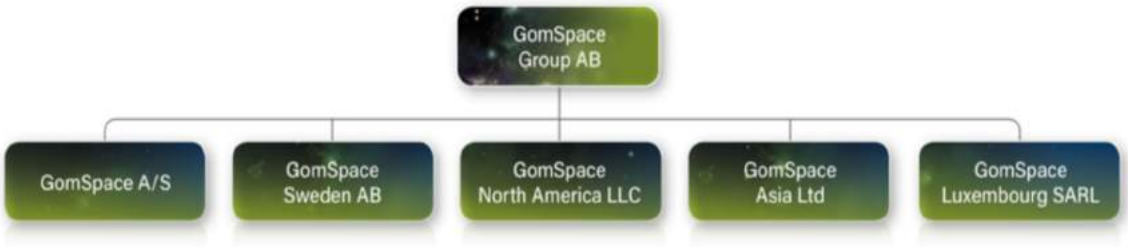

Figure G.2: GomSpace Group structure. Image Credit: GomSpace Group AB [158].

G.3.1 Ownership

GomSpace Group AB in own by different shareholders. With the last preferential rights issue nearly doubling the number of shares, the company's number of outstanding shares on March 31, 2019 was 52,274,803. At the last annual general meeting on April 26, 2019, the lower and upper number of shares limits were augmented to 50M and 200M respectively. Similarly, the share capital thresholds were increased to SEK 3.5M and SEK 14M [162]. This share can be distributed in 4 different owner groups, as shown in table G.1.

Table G.1: GomSpace Group AB distribution[163].

Owner Group	Shares	Holding
General Public	31,000,267	59%
Private Companies	11,102,623	21%
Institutions	8,519,781	16%
Individual Insiders	1,652,132	3%

There were 10,315 registered shareholders after the last shares issue. The Board of Directors and the Management hold 5,338,646 and 1,562,132 shares respectively, making a total of 13.20% of the company's shares. The main public shareholders can be seen in table G.2, representing a 30.6% of the total shares. It is important to point out that all the company shares are of one class, meaning that each share entitled to one vote at shareholders meetings [163], [158].

Table G.2: *GomSpace Group AB main public shareholders [164].*

Shareholder's name	Percentage of share capital and votes
JML Invest ApS	12.5%
Hansen & Langeland ApS	10%
MediumInvest A/S	5%
Boeran Innovation A/S	3.1%

G.3.2 **Board of directors**

The Board of Directors leads the group to maintain and accomplish the mission, vision and strategic plan goals. Among their duties, they approve major policies, make major decisions, oversee performance or choose a CEO. The board of directors at GomSpace must be more than 3 and no more than 7 members [165]. They currently are:

- **Jukka Pertola - Chairman of the Board:** Mr. Pertola has been the Chairman of the Board and a member since 2016. He is also Chairman of the Board of Directors at Siemens Gamesa Renewable Energy A/S, IoT Denmark A/S or the Danish Academy of Technical Sciences. He has more than 20 years of experience in different fields management, in addition to 10 years as a Board member. Born in 1960, he holds an M.Sc. in electrical engineering from the Helsinki University of Technology . He holds directly 40,000 shares of GomSpace [165].
- **Jesper Jespersen - Vice Chairman:** Mr. Jespersen is also a Chairman of the Board of Directors at AnyBody Technology A/S and Board member at BBHS A/S and several companies within the NOVI/BOREAN group. His 18 years of CEO experience include Novi A/S. Born in 1946, Mr. he obtained a Master in business administration from the Aarhus Business School and a Mini Master in business administration from Stanford University. He holds directly 50,000 shares of GomSpace [165].
- **Steen Lorenz Johan Hansen - Board member:** Mr. Hansen is Chairman of the Board of Directors at Travelcon A/S and Beach Lodge ApS. Born in 1948, he has 39 years of experience as CEO and holds a M.Sc. in electrical engineering from the Technical University of Denmark. He is the Managing Director, CEO and majority shareholder of Hansen & Langeland ApS, therefore holding indirectly 5,248,646 shares of GomSpace (10%) [165].
- **Hans Henrik Schibler - Board member:** Mr. Schibler is a Board member since spring 2019. With 10 years of experience as Chief Financial Officer (CFO) in large scale business, he holds this position at EVRY ASA and used to do at ISS Norway. Born in 1978, he holds a Master's degree in Economics and Business Administration from the Copenhagen Business School. He does not own any GomSpace share [165].

G.3.3 **Executive Management**

The Executive Management is led by the CEO and heads the organization towards the board directions. Among their duties they make operational decisions and policies and keep the board informed and educated through well-documented recommendations and information. GomSpace's Executive Management is composed by 5 key members:

- **Niels Buus - CEO:** Mr. Buus has been GomSpace CEO since 2014. He has more than 20 years of experience in the defence and security business. He is currently the Chairman of the Aalborg University Nomination Committee, Board member of the Danish Defense and Security Industries Association and partner and CEO of Longbus Holding ApS. Born in 1957, he holds a M.Sc. in leadership and strategy from the London Business School, a M.Sc. in applied optics from the Imperial College and a M.Sc. in mechanical engineering in optics from the Aalborg University. He holds directly 38,000 company shares as well as indirectly 1,221,759 through Longbus Holding ApS. His wife holds directly 2,000 [158].
- **Troels Dalsgaard Nørmølle CFO:** Mr. Nørmølle has been GomSpace's CFO since 2014. He is currently a partner of Skallerup Management and Skallerup Invest IVS, were he is also the CEO. He has more than 10 years of experience in accounting at EY, PwC or Aalborg Boldklub. Born in 1986, he holds a Graduate Certificate in business administration from the Aalborg University. He directly holds 1,000 shares while indirectly holding 293,300 shares through Skallerup Invest IVS. His children hold 3,000 directly [158].
- **Dan Ulrich - Chief Compliance Officer (CCO):** Mr. Ulrich used to be GomSpace CTO until December 2018, when he took the CCO position. He has more than 20 years of experience with complex technology and business, new business development and development in Airspace and Defence. Born in 1962, he is not involved in any other assignments. He has a M.Sc. in chemistry, an Industrial PhD from the Technical University of Denmark and an executive MBA from the Ashridge Management College. He holds directly 3,076 GomSpace shares [[158].
- **Morten Hvidberg Jeppesen - CTO:** Mr. Jeppesen started as GomSpace CTO in December 2018 and is not involved in any other outer assignment. He has experience in several international engineering companies such as MAN Diesel & Turbo and BAE Systems Applied Intelligence A/S. Born in 1975, he holds a M.Sc. in digital signal processing from the Aalborg University. He holds directly 4,655 GomSpace shares [158].
- **Peter Høy - Chief Procurement Officer (CPO):** Mr. Høy is GomSpace CTO since August 2018 and is currently not involved in any other outer assignment. One year earlier he joined GomSpace as Production Director. His vast experience at executive management positions were achieved in companies such as EuroCom Industries A/S or Thrane & Thrane A/S. Born in 1957, he holds a M.Sc. in economics & business administration from the Aarhus School of Business. He holds directly 3,370 GomSpace shares [158].

G.3.4 **Employees**

After the 2018 employee's reduction, GomSpace Group AB was formed by 201 employees on March 31st, 2019. They are classified whether they work within technology, manufacturing, sales and distribution or administration. They are 97, 58, 19 and 27 respectively. The number of employees has decreased by 30 since the end of 2018 due to overcapacity, mostly within technology (18) and manufacturing (11). This is related to the payment delays from Sky and Space Global and the cease of this project activities. By the end of 2018, the distribution of employees by subsidiary was as shown in table G.3 [158].

GomSpace define in their webpage the working culture to be informal and with transparent communication. The organization is supposedly built upon multidisciplinary skills and engineering passion. They also state that the company is about people, as *"Treasuring our Employees is Essential to Treasuring our Customers" [166]*. Thus, 5 values are defined to serve as a guidance and back the company key behaviours. Those are **quality** of their products and services, **customer focus** from sales contact to product delivery, **leadership** as a company and individuals in their fields, **ethics** in all aspects of their business and **diversity** in teams with people from different backgrounds bringing valuable differences.

Table G.3: GomSpace Group AB subsidiary employees distribution on December 31st, 2018 [158]

Subsidiary Name (Country)	Number of employees
GomSpace Group AB (Sweden - Parent Company)	2
GomSpace A/S (Denmark)	200
GomSpace Sweden AB (Sweden)	20
GomSpace Luxembourg S.A.R.L. (Luxembourg)	7
GomSpace ASIA Pte. Ltd. (Singapore)	1
GomSpace North America LLC (USA)	1
TOTAL	231

GomSpace seeks for employees that would live their values with integrity and passion, committing to excellence and open communication in any job situation. This would help to achieve the company's full potential. It is also backed up with complete collaboration between talented GomSpace people, making cooperation an important aspect to the company [166].

The GomSpace webpage presents the experiences of 6 company employees. All of them highlight the informal working environment, the presence of the company values, the perspective of growth the company aims and the achieved sector leadership. More technical employees showed excitement over their possibilities to develop projects with cutting edge technology as well as the satisfaction when their creations are put on orbit. Company social events with family members were mentioned. Together with flexible times, they contribute to less stressful jobs and effective results [167]. The descriptions compiled at the webpage only collect positive aspects of working at GomSpace. A sole external employee review was found, in which a system engineer summed up his job interview. He stated in 2016 that the recruitment process took about a week, the video chatted with GomSpace CEO and CTO and finally got hired. His experience was neutral, but they were reasonable with his fair compensation requests [168].

G.4 EO Market Segment & Requirements

This section is divided between GomSpace's business model, business segments and solutions.

G.4.1 Business Model

GomSpace bases its competences in the radio technology. This technology has turned out to be specially interesting for Nanosatellites due to its size and capabilities. Consequently, the company offerings are dedicated to the Nanosatellites sector. The revenues come from 5 different sources, as shown in the business model from figure G.3. They are the subsystems, complete platforms, payloads, constellation management and additional services [169]. The payloads and subsystems are deeply explained in section G.5 while the platforms, constellation management and additional services are done so in section G.6.

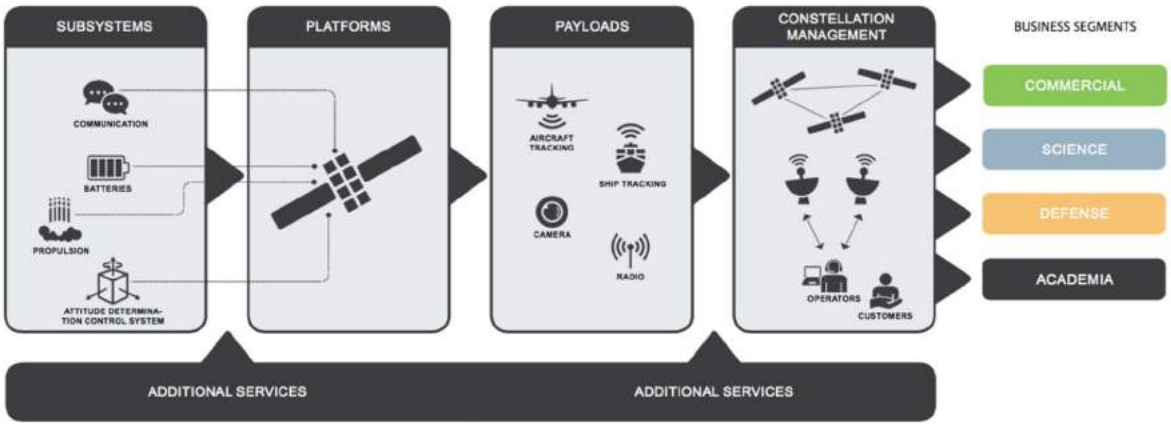

Figure G.3: GomSpace Group AB business model. Image Credit: GomSpace Group AB [169].

The company profitability relies on the fact that the engineering time can be re-used in similar projects. The modularization and versatility of the components make them adaptable to be incorporated in CubeSats with diverse purposes and missions. GomSpace supplies components as well as complete projects, but their main goal seems to become a full-service provider. They are becoming reluctant to supply components to competing satellite manufacturers while the launch services and constellation management functions keep building up [169]. Figure G.3 also presents the four business segments in which GomSpace operates.

G.4.2 Business Segments

GomSpace focuses its sales in 4 different business segments; Academia, Commercial, Defense and Science. These four segments divided the revenues of GomSpace for the years 2017, 2018 and the first quarter of 2019 (Q1 2019) as shown in table G.4. The biggest segment is the Commercial, due to the Sky and Space Global and AISTECH major contracts. The Science segment has gained more weight with time, becoming the second most important segment and diminishing the Academic. The Defense segment appears with a marginal revenues percentage in last position. It is observable that almost three fourths of the revenues of GomSpace come from the Commercial segment [169].

Table G.4: *GomSpace Group AB business segments revenues distribution [169].*

Segment	2017	2018	Q1 2019
Commercial	75%	79%	74%
Science	8%	11%	13%
Academic	13%	7%	9%
Defense	4%	3%	4%

The GomSpace business segments also have different importance around the world. The company distributes its sales revenues in 6 geographical regions. Table G.5 presents the percent of revenues obtained in this regions in 2018 as well as the overall share each region has in GomSpace sales [169].

Table G.5: GomSpace Group AB business segments revenues distribution by geographical region in 2018 [169].

Region	Academia	Commercial	Defense	Science	Overall
Sweden	18%	0%	0%	82%	1%
Denmark	48%	47%	0%	14%	2%
Rest of Europe	3%	83%	0%	14%	57%
USA	0%	61%	38%	0%	5%
Asia	22%	53%	12%	13%	15%
Rest of the World	5%	95%	0%	0%	20%

GomSpace divides its major goods or services between satellite solutions and platforms, payloads and subsystems. The satellite solutions refer mostly to entire CubeSats platforms while the other group gathers the subsystems and payloads sold separately. During Q1 2019, 75% of revenues were from satellite solutions while only 25% were due to the second group [169].

G.4.3 **Solutions**

GomSpace offers solutions in 6 different areas thanks to their Nanosatellite products. They state that Cubesats should provide revenue or mission critical services to their owners. GomSpace facilitates the projects required to achieve such things. Those projects are turn-key and fully transparent to the customer, using internationally recognized standards. Moreover, GomSpace claims to have a flexible portfolio. It benefits from building blocks for radio payloads, constantly innovated new applications and in-orbit second-to-none performance [170].

G.4.3.1 Global Tracking

The global tracking of assets by satellites is starting to be widely generalized. The information broadcasted is standardized and gains relevance with time. GomSpace has strong experience with vessels and aircrafts tracking through the reception of AIS and ADS-B signals respectively. These technologies have been improved through their GOMX-1 and GOMX-3 missions. Thus, GomSpace is able to develop entire on-demand Nanosatellite constellations for tracking based on high coverage and revisit times. In addition, other tracking solutions can be designed using their radio technology payloads building blocks. Some companies like A&M or AISTECH already benefit from this solution [171].

G.4.3.2 Internet of Things

Full two-ways communications between various devices is gaining importance nowadays. GomSpace provides it through satellite based IoT, allowing remote management of assets, herd tracking, fleet management or smart metering. In order to implement the IoT technology, GomSpace based the solution on their RF and signal processing experience. That includes low-power front-end electronics, SDR, signals ranging from high-frequency to Ka-band, the utilization from simple monopole antennas to complex patch arrays and complex signal processing. Finally, GomSpace also assists with the corresponding IoT ground terminals [172].

G.4.3.3 Communications

GomSpace provides a more generalized communications solution than the previous ones. Based on the aforementioned RF and signal processing experience, the company developed the bespoke communications system. It includes advanced features such as ISL capabilities, satellite power generation and distribution to support demanding radio payloads and station keeping capabilities. This technology was tested onboard the GOMX-3 mission. Sky and Space Global benefits from it [173].

G.4.3.4 Remote Sensing

GomSpace views EO Nanosatellites as a cost-efficient entry level platform before going to higher resolutions. These cost-effective constellations can provide medium resolutions with high temporal update rates. GomSpace has developed different systems for EO purposes such as IR, hyperspectral and optical (NanoCam C1U) sensors. The GOMX-4 mission aims to demonstrate new hyperspectral imaging payloads for GomSpace [174].

G.4.3.5 Defense and Security

Military, intelligence and security solutions have special requirements that GomSpace claims to be able to provide. Tested and well-proven platforms may include the previous 4 solutions; tracking, IoT, communications and remote sensing. However, unique defence projects also need skilful handling. For instance, discretion, strong data encryption and other cyber-security measures. New space-based capabilities integrated into Command, Control, Communications, Computer, Intelligence, Surveillance, and Reconnaissance (C4ISR) infrastructures and additional Electronic counter-countermeasures (ECCM) resilience are required. GomSpace has vast experience in this field, participating in projects like the Ulloriaq Arctic Surveillance/GOMX-4 project with the Danish Defense or the HawkEye360 [175].

G.4.3.6 Science Missions

According to GomSpace, science missions to understand the universe and beyond can get benefited from cost-efficient Nanosatellites. They can also be used as a first approach before big ticket missions. The company offers science customers a flexible product portfolio that can result in effective mission platforms. They may include mature propulsion technology, ideal for deep space attitude control, formation flying, rendezvous and docking. GomSpace claims to be experienced in space missions, understanding and supporting them with low costs and risks [176].

G.5 Satellite Payloads and Subsystems

GomSpace bases its production of satellites in CubeSats. Each CubeSat contains a number of subsystems in order to perform all necessary functions to operate in space. They are allocated in its 1U unit cubes. The standardization of the 1U unit cubes made it possible for GomSpace to standardize the subsystems as well. Thus, they can produce a large quantity of them, providing high quality, low lead time and attractive costs. Similarly, a payload is a subsystem that has the purpose to execute the task that defines the satellite mission. They are also standardized for the CubeSat 1U units but need to be more technologically advanced, developed and refined to meet each mission's objective [177].

GomSpace has developed, qualified and in-orbit validated payloads and subsystems through the GOMX flight test program. Their worldwide customers operate in many business segments, validating their products. The COTS nature of these standard components makes them reliable plug-and-play solutions. This allows companies to focus on their mission objectives [178].

G.5.1 Mission Payloads

The strength of GomSpace payloads relies on their state-of-the-art radio technology. The systems of their payload solutions are specified, designed and software enabled to meet all requirements. GomSpace payload strengths are based on advanced tailored radio payload solutions, advanced signal processing founded on SDR and simple to advanced antennas ranging from 0 GHz to 40 GHz. Their payloads are grouped in Aircraft Tracking ADS-B, Ship Tracking AIS, Software Defined Radio (SDR) and Optical EO [177].

G.5.1.1 Aircraft Tracking ADS-B

The NanoCom ADS-B together with the NanoCom ANT1090-P patch antenna form a system to pick up airplane broadcasted ADS-B signals worldwide for tracking. The receiver gets the ADS-B signal transmitted by an aircraft at 1,090MHz with its ID, position and status. The system has already been developed and tested in space through the GOMX programs.

The NanoCom ADS-B consists on an in-orbit reconfigurable Field-Programmable Gate Array (FPGA) board compatible with CubeSats. It only requires about 0.3U of a CubeSat volume and consumes around 0.5W of power. The maximum number of data packages per second it can receive is approximately 800.

The NanoCom ANT1090-P patch antenna can be connected to a GomSpace SDR transceiver. It is available in a passive or active version. Its flexible sandwich construction allows to mount it in different structures. Its integrated structure with low noise amplifiers and filters results in low losses and optimum RF noise figure performance. Its gain is of 4.5 dB.

G.5.1.2 Ship Tracking AIS

The Satlab QubeAIS Software-Defined AIS Receiver is a fully self-contained SDR intended for space-based ship tracking. It weighs less than 55g, consumes about 0.8W at full load and has a sensitivity of −113dB. It is software reconfigurable for AIS at 162MHz and long range at 156.8MHz. The QubeAIS allows to download raw RF spectrum samples, uses the CubeSat Space Protocol (CSP) protocol, has low noise amplifiers, RF filters and data storage, and is delivered with an easy-integration software library. It operates with a passive antenna connected through MCX or SMA.

G.5.1.3 Software Defined Radio (SDR)

The NanoCom SDR is a platform with sensing and communication capabilities that uses powerful and advanced FPGA technology. It is composed by the NanoDock SDR motherboard, the NanoMind Z7000 On-Board Computer (OBC) and FPGA and the NanoCom TR-600 transceiver. The three become a modular CPU, FPGA and radio for small satellites. This in-orbit programmable device weights around 300 g and can adapt to many configurations with its high versatility and low volume. The modularized architecture, known as the GomSpace Mother/Daughter board concept, allows 1 FPGA module and up to 3 transceiver modules. The FPGA can be used for advanced signal processing and detection techniques, while the transceiver modules perform S-band ground link and S-/K-band ISL. The modules are explained in sections G.5.4.2 and G.5.3.1 respectively.

G.5.1.4 Optical Earth Observation

The GomSpace NanoCam C1U is a high performing, flexible and modular camera system for optical EO missions. The lens, the processing board and the software are COTS components. The system is hosted in a standard 1U CubeSat structure. 3 different lenses are available; 8 mm, 35 mm or 70 mm, ordered in increasing resolution. It weighs about 170g with the first two lenses and 280g with the third. It is a 3-megapixel colour sensor capable of on-board advanced data processing and storage using a high-performance processor. With 512 MB of RAM and 2 GB of solid-state image storage, it can deliver images in RAW, BMP and JPEG formats.

G.5.2 Power Systems

GomSpace product line covers all the required parts of a satellite power system. They consist of the solar panels, the power supplies and the batteries. The first provides the power to the satellite, the second controls it and the third stores the unused generated power [179].

G.5.2.1 Power Supplies

GomSpace offers 2 power supply models; the NanoPower P31u and the NanoPower P60. The first is suitable for smaller platforms than a 3U CubeSats, while the second power supply is recommended for bigger satellites. Both have been extensively in-orbit tested and flown in several missions and are compatible with the GomSpace BP4 and BPX battery packs.

- **NanoPower P31u:** It is an Electrical Power Subsystem (EPS) optimal for 1U and 2U CubeSat platforms with a mounted on-board battery. It delivers up to 30 W and employs a strictly KISS design philosophy. It incorporates a 20 W h, 8 V lithium ion battery pack.
- **NanoPower P60:** It is a modular EPS consisting of a P60 Dock motherboard hosting 1 modular Array Conditioning Unit and up to 4 Power Distribution Units. It has synchronized out-of-phase converters for low electromagnetic interference operations. The battery voltage can be 16V or 32V [180].

G.5.2.2 Battery Packs

The GomSpace battery packs are composed by COTS lithium-ion cells proven in space. 2 packs are offered; the NanoPower BP4 and the NanoPower BPX. The former is a standard 4 cells battery module while the latter is a high capacity 8 cells battery pack with an autonomous heater system.

- **NanoPower BP4:** It is offered in 2 variants, delivering 2,600 mA h at 14.8 V or 5,200 mA h at 7.4 V. It weighs about 270 g and both versions deliver 38.5 W h. The NanoPower BP4 is recommended to pair with the NanoPower P31u for a longer CubeSat life.
- **NanoPower BPX:** It is a customizable battery pack with a capacity of 77 W h. 3 configurations are available; with nominal voltage of 7.4V at 10,400mAh, 14.8V at 5,200 mA h or 29.6 V at 2,600 mA h. Moreover, it is possible to expand the system by connecting any number of packs in parallel or serial.

G.5.2.3 Solar Panels

GomSpace solar panels are mounted on aluminium plates outside the satellite. They are based on 30% efficient ITAR free cells and integrate magnetic-torquers, coarse sun-sensors and temperature sensors. Each cell produces 1.15 W at LEO. They are assembled in a space qualified triple junction. The company offers 3 solutions; the NanoPower MSP for 6U and 12U structures, the NanoPower DSP for 3U and 6U CubeSats and the NanoPower P110 for 1U and 2U.

- **NanoPower MSP:** It is a modular system with the cell plates shielding the internal CubeSat components. Many cell setups are possible on each CubeSat face depending on its mission. It allows to cover all the satellite surface besides the antennas and sensors, providing optimum energy production.
- **NanoPower DSP:** It is composed by three panels connected with spring loaded hinges. One panel covers the internal CubeSat systems while the others are folded at launch and deployed when in service. Two versions are available; the 135° version and the 90° version. The main panel of the latter attached to the satellite doesn't have solar cells, while the former has. Moreover, the 135° version includes two GomSpace fine sun sensors.
- **NanoPower P110:** It is an integrated side panel with 2 solar cells. It includes a magnetorquer, a sun sensor and a temperature sensor. Each panel covers a 1U CubeSat Unit side.

G.5.2.4 Power Packs

Regarding the needs of GomSpace customers, the company has tailored solutions for 3U, 2U and 1U CubeSats. The so called **NanoPower Power Packs** systems are full power solutions. They include maximum power point tracking, charging management, managed power distribution and single board batteries that use little space. The 1U Power Pack includes 1 NanoPower P31u power supply with battery and 6 NanoPower P110 solar panels. The 2U Power Pack is composed by 1 NanoPower P31u power supply with battery and 10 NanoPower P110 solar panels. Finally, the 3U Power Pack has 1 NanoPower P31u power supply without battery, 1 NanoPower BP4 battery and 14 NanoPower P110 solar panels. All the packs come with a harness kit to connect the components, 6 coarse sun sensors and 3 magnetorquers for attitude determination and control.

G.5.3 Communication Systems

GomSpace radio communication products are grouped into space segment and ground segment. They can transmit and receive telemetry, satellite control and payload data [181].

G.5.3.1 Space Segment

Communication products mounted on-board of CubeSats provide ground link and ISL communications. GomSpace is currently offering high speed S-band and UHF/VHF radio communication products. This includes transceivers and antennas [181].

- **NanoCom SR2000:** It is a flexible, ready-to-use S-band transceiver build on GomSpace SDR platform. It supports ground link and ISL communications. Fully configurable in-orbit, it uses a flexible layer-3 bandwidth up to 1.25 Mbps. Recommended to use with the S-band patch antenna ANT2000.
- **NanoCom AX100:** It is an UHF/VHF communication miniaturized transceiver. Its modularity allows redundancy and flexible link frequency configurations in UHF or VHF. The data rates go from 0.1 kbps to 115.2 kbps. Recommended with the NanoCom ANT-6F or NanoCom ANT430 antennas.
- **NanoCom TR-600:** It is a customizable RF front end transceiver module mostly used with the GomSpace SDR platform. In-orbit reconfigurable, it incorporates an AD9361 transceiver, operates from 70 MHz to 6 GHz, has a tunable channel bandwidth from 200 kHz to 56 MHz and includes EEprom for persistent configuration storage.
- **NanoCom ANT2000:** It is a S-band patch antenna for high speed communication. It equips power and low noise amplifiers, lowering the losses and optimizing the RF. Its gain is 8 dB.
- **NanoCom ANT430:** It is an omnidirectional canted turnstile UHF antenna for 1U, 2U and 3U CubeSats. It consists of 4 monopole antennas with a gain from 1.5 dB to −1 dB.
- **NanoCom ANT-6F:** It is a modular, close to omnidirectional canted turnstile antenna, similar to the ANT430. However, the ANT-6F is suitable for 6U CubeSats and presents 2 versions; for UHF and VHF.

G.5.3.2 Ground Segment

The GomSpace ground segment products allow customers to setup a ground station to communicate with their satellites. They provide ground station radio units, antennas and a mission computer with software.

- **NanoCom GS100:** It is a ground station dual-radio solution for UHF and VHF. It incorporates 2 internal NanoCom AX100 radio modules, providing polarization diversity and simplified hardware development.
- **NanoCom GS2000:** It is a S-Band ground station radio transceiver. It is mounted in a 2U rack-cabinet, is supplied by 28 V and can connect 1 receiving and 1 transmitting antennas.
- **NanoCom AS100:** It is an UHF ground station antenna with a satellite tracking rotor. It is composed by a 4 m high tower with 2 Yagi antennas, a rotor controller, an elevation and an azimuth rotor. It has enough gain to perform LEO satellite communications (17 dB).
- **NanoCom AS2000:** It is a ground station antenna with satellite tracking rotor for LEO communications. It is composed by a 1.2m S-band dish antenna, 2 UHF Yagi antennas and a rotor system similar to the NanoCom AS100.
- **NanoCom MS100:** It is a mission computer with software in a 6 kg rack. It has Linux operating system, an Intel Xeon E3-1220 3GHz processor, 500GB of solid storage and 4GB of RAM memory. The software incorporates a rotor controller for satellite tracking and radio Doppler compensation. It is a hub between the satellite and the user workstation.
- **NanoCom GND UHF/VHF:** It is the GomSpace solution for a complete UHF/VHF ground station. It consists on a NanoCom AS100 antenna tower, a NanoCom GS100 transceiver and a MS100 mission computer with software. The ground station can be operated and controlled via Ethernet or Internet.

G.5.4 Command and Data Handling

GomSpace offers powerful and miniaturized OBCs to control satellite operations and payloads. They also offer the required software to execute any mission. The philosophy of the software is based on a network vision, where the subsystems are autonomous nodes. They communicate freely to each other but can be operated and controlled from the ground station. The CSP physical networks and the router-like role of the transceivers are essential. This distributed architecture is supported by the hardware platform. When combined with the software, a small and low risk fully integrated satellite is achieved [182].

G.5.4.1 NanoMind A3200

This highly miniaturized OBC is composed by the actual A3200 OBC, a 3-axis magnetometer, a 3-axis gyroscope and coil-drivers. The first is an efficient system for space applications but has limited resources. The rest are used for attitude control. The OBC incorporates a high-performance AVR32 MCU with advanced power saving features. It also hosts a 512kB build-in flash and a 128MB NOR flash for storage, in addition to 32kB of FRAM for persistent configuration storage. Its low consumption (about 0.17W) makes the NanoMind A3200 ideal for CubeSats, Nanosats and Microsats.

G.5.4.2 NanoMind Z7000

This powerful ARM and FPGA OBC is GomSpace solution for demanding CubeSat applications. It is used for SDR, signal and image processing or ISL. The modular Z7000 is composed by a powerful dual ARM Cortex A9 MPCore and a flexible FPGA module with 125K logic cells. It has 1 GB of DDR3 RAM memory and 32GB of storage. The NanoMind Z7000 has Linux as operative system. Its thermal load is controlled by a precision milled anodized aluminium heat sink that also provides electromagnetic shielding. Its power system is dually divided between the ARM and the FPGA. Its maximum power consumption is of 2.3 W.

G.5.4.3 Platform Software

GomSpace offers the software that, integrated in the satellite OBC and the ground station, allows clients to command their satellites, schedule activities and get telemetry data. This software is the Command & Management Software Development Kit (SDK) by Linux. It can be installed in both NanoMind A3200 and Z7000 OBC and in the NanoCom MS100 ground station computer. It uses CSP communication with the drivers, allowing the user to modify parameters and obtain important OBC data.

The SDK software includes a set of advanced and feature rich GomSpace library modules. It has a Flight Planner to schedule and manage satellite commands during space operations and allows the user to perform space and ground modules housekeeping.

The telemetry dashboard GSWeb is a web-based tool that displays, plots and stores the historic and real-time satellite telemetry data. It is highly customizable and can be integrated with various libraries. The tool incorporates a few subpages, each of which displays a number of modules previously configured. Due to its browser-based nature, multiple users can review the real-time data simultaneously [157].

G.5.5 Attitude and Orbit Control Systems

The GOMX IOD program has given GomSpace expertise in CubeSats attitude and orbit control systems design. They are the ADCS system and the propulsion system.

G.5.5.1 ADCS System

The objective of the ADCS system is to control the navigation of the satellite in terms of angle to the sun, distance to the Earth or other satellites or to meet the critical mission requirements. It consists in some subsystems that can be hosted in a single ADCS box. However, it is often not adequate for Nanosatellites. The modularization of GomSpace CubeSats facilitates to provide a high-performance solution with separated subsystems [183].

- **Magnetorquer:** GomSpace offers 2 different devices; the **NanoTorque GST-600** and the **NanoTorque Z-axis Internal**. The first one is a 3-axis magnetorquer designed especially for 6U CubeSats or larger. The second one is a single axis magnetorquer for smaller Nanosats. While the GST-600 is composed by a single air-torquer and two magnetorquer-rods, the Z-axis Internal only has an air-torquer. Their torque moments are bigger than 300 m A m for each axis and of 139 m A m respectively.
- **Magnetometer:** The **NanoSense M315** is a compact low noise 3-axis magnetometer intended for high performance ADCS systems. By being small reliable and light, it becomes flexible and can be placed away from magnetic disturbance sources.
- **GPS receiver:** The **NanoSense GPS kit** includes a customized dual-frequency NovAtel OEM-719 GPS receiver module and an antenna. The latter is chosen between the Inventek ACTPAT154-01-IP or the Tallysman TW1322. It has no COCOM imitations, requires 3.3 V and its position and velocity precision are of 1.5 m and 0.03 m/s respectively[184].
- **Reaction wheel:** GomSpace reaction wheel solution, with high torque and momentum storage capability is the **NanoTorque GSW-600**. Intended for 6U or 12U CubeSats, it compactly packs a 4-wheels redundant setup as a pyramid or as a 3 + 1 without mounting bracket. It is designed for long life, with hybrid bearings, a brushless motor, a precisely balanced flywheel, integrated electronics, lubricant free and an enclosed design.
- **Fine sun sensors:** The **NanoSense FSS** is GomSpace high precision and ultra-compact fine vector sun sensor. It comes with a digital interface (I2C), a wide field-of-view and an elevator unit. It is flexibly mounted, consumes low power and weights 2.2 g.
- **ADCS Software:** The **GomSpace ADCS SDK** software allows mission satellite control through de-tumbling and stabilization. Installed in the NanoMind A3200, it is built on top of the Command & Management SDK, where low level and platform setups are handled. The software allows communications with all the sensors, actuators and propulsion systems to perform advanced positioning, attitude determination and attitude control [185].

G.5.5.2 Propulsion Systems

GomSpace offers cold gas propulsion systems that are compatible with the company's ADCS system. They offer 2 different solutions; for a 6U CubeSats and larger or for 2U and 3U satellites. They use Butane as the cold gas, which is ejected through 4 thrusters to control the satellite in any direction. The gas consumption is very low, ensuring a mission lifetime operative duration. With that, a delta-V from 8 m/s to 13 m/s is provided. The 2 systems are:

- **NanoProp CGP3 3U Propulsion:** It is a MEMS propulsion module for 2U and 3U CubeSats. The module is composed by 1 butane tank, 4 individually controllable thrusters, closed loop thrust control and integrated flow sensors that provide real time thrust measurements. It has a trust of 1mN, a total impulse of 40Ns, its wet mass is of 350g and only requires about 0.5U CubeSat volume units.
- **NanoProp 6U Propulsion:** It is a MEMS cold gas propulsion module for 6U and beyond CubeSats. It is a development of the NanoProp CGP3 3U Propulsion, being similar in almost all the aspects. However, it incorporates 2 butane tanks, a trust of 10 mN, a total impulse of 80 N s, a wet mass of 900 g and a volume of 2U wide and 0.5U high.

G.6 Platforms and Services

The company offers products in the 5 groups of its business model; subsystems, payloads, complete platforms, constellation management and additional services. They are considered as the company's main sources of revenue. This chapter will approach the 3 last groups [186].

G.6.1 Satellite Platforms

For over 10 years GomSpace has been involved in the NewSpace sector. Their broad subsystems portfolio can be configured in many different platforms to fulfil client's mission requirements. The company states that their strengths rely on their products flexibility and the successful results in development, qualification and validation of the GOMX flight test program.

GomSpace currently offers well proven 1U, 2U 3U and 6U CubeSat platforms. In addition, the Q1 2019 Interim report from GomSpace Group AB mentions that the new 8U Platform is already being offered, even though it is not available in their web page. The company is investing many resources to develop new 12U and 16U CubeSat architectures as the market demands are evolving. An example for the 12U could be the M-ARGO mission [187].

G.6.1.1 1U and 2U CubeSat Platforms

The smallest available Cubesats in GomSpace are ideal for simple experiments in-space involving radio communications, EO and academic programs. They are also desirable for nanosatellite integration and in-space operation training. GomSpace Only describes the 1U platform, considering the 2U as an expansion of the previous.

The satellite and its components are tested and qualified by a specific GomSpace program. It covers thermal cycling, vibration, thermal stress, radiation and heated vacuum. The desired platform is delivered either ready to integrate an external payload or upgraded with the NanoCam C1U camera payload. The platform is equipped with different subsystems. They have been in development since 2014 [188].

- **Power System:** It consists on the 1U Power Pack with a NanoPower P31u and 6 NanoPower P110 solar panels.
- **The Mechanics:** It is described as the 1U Cubesat structure with full Harness Set.
- **The Command and Management System:** It is based on the miniaturized OBC NanoMind A3200, the preinstalled software package for satellite control and the mission library for flight planning and data collection.
- **The Communications System:** It consists on the UHF NanoCom AX100 transceiver, the NanoCom ANT430 and the aforementioned OBC NanoMind A320.
- **The ADCS System:** It incorporates the ADCS software and integrated magnetorquer NanoTorque GST-600 for basic stabilization and satellite alignment.

GomSpace can deliver a standard platform without payload integration in 4 to 6 months after the reception of the order. The 1U platform technical information is shown in table G.6.

Table G.6: GomSpace 1U CubeSat Platform technical information. Adapted from GomSpace Group AB [188].

Platform		Payload	
Size	1U	Payload Space	0.3U
Peak Power	3.4W	Av. Payload Power	Depends on orbit
Battery Capacity	20 Wh	Max. Payload Mass	1 kg
Platform Mass	0.95 kg	Payload Interfaces	CAN bus
Platform lifetime	< 1 year	Power Bus	3.3V or 5V

G.6.1.2 3U CubeSat Platform

GomSpace 3U standard platform is based on the successful IOD GOMX-3 mission launched in 2015. They state that this platform is useful to perform air traffic data collection through ADS-B, sea vessels monitoring though AIS, professional radio and IoT data communications, IOD and science missions. This CubeSat has large payload volume, small mass, precise ADCS and enough power capacity to sustain a commercial radio payload for a full duty cycle.

The platform and its subsystems completed the GomSpace program for testing and validation in thermal cycling, vibration, thermal stress, radiation and heated vacuum. GomSpace delivers the desired platform with standard subsystems and ready to integrate an external payload. However, upgrades can be included with extra battery packs, deployable solar panels, fast data downlink, an on-board propulsion system and a more precise ADCS system [189].

- **Power System:** It consists on the 3U Power Pack with a NanoPower P31u, the NanoPower BP4 battery pack and 14 NanoPower P110 solar panels.
- **Mechanics:** It is described as the 3U Cubesat structure with full Harness Set.
- **Command and Management System:** It is based on the miniaturized OBC NanoMind A3200, the preinstalled software package for satellite control and the mission library for flight planning and data collection.
- **Communications System:** It consists on the UHF NanoCom AX100 transceiver, the NanoCom ANT430 and the OBC NanoMind A3200.
- **ADCS System:** It incorporates the ADCS software for fine stabilization, a NanoMind A3200 ADCS computer, the NanoSense GPS kit module, 1 reaction wheel for 1-axis control, 6 NanoSense FSS fine sun sensors and a NanoSense M315 magnetometer.

GomSpace is able to deliver a standard platform without payload integration in 4 to 6 months after the order has been received. The 3U platform technical information is shown in table G.7.

Table G.7: GomSpace 3U CubeSat Platform technical information. Adapted from GomSpace Group AB [189]

Platform		Payload	
Size	3U	Payload Space	1.8U
Peak Power	8W	Av. Payload Power	Depends on orbit
Battery Capacity	38 Wh	Max. Payload Mass	1.8 kg
Platform Mass	2 kg	Payload Interfaces	I2C, UART, CAN bus
Platform lifetime	< 5 years	Power Bus	3.3V or 5V

G.6.1.3 6U CubeSat Platform

The 6U Cubesat platform is based on the IOD GOMX-4 mission launched in 2018. Similarly, to the 3U Cubesat, this platform is useful to perform air traffic data collection through ADS-B, sea vessels monitoring though AIS, professional radio and IoT data communications, IOD and science missions. In addition, the 6U platform is ideal to form satellite constellations.

It also has completed the GomSpace program for testing and validation in thermal cycling, vibration, thermal stress, radiation and heated vacuum. The platform is delivered with standard subsystems and ready to integrate an external payload. Upgrades can be added to the standard configuration. They include improved pointing, position knowledge and control through extra ADCS system elements, a cold gas propulsion system for orbital manoeuvres or increased available payload and platform power through larger deployable solar panels [190].

- **Power System:** It consists on a NanoPower P60 EPS, a NanoPower BPX battery pack and NanoPower MSP solar panels as customized.
- **Mechanics:** It includes the 6U Cubesat structure with full Harness Set and internal mounting rings.
- **Command and Management System:** It is based on the miniaturized OBC NanoMind A3200, the preinstalled software package for satellite control and the mission library for flight planning and data collection.
- **Communications System:** It consists on the UHF NanoCom AX100 transceiver, the NanoCom ANT430 and the OBC NanoMind A3200.
- **ADCS System:** It incorporates the ADCS software for fine stabilization, a NanoMind A3200 ADCS computer, the NanoSense GPS kit module, 4 reaction wheels in the NanoTorque GSW-600, 6 NanoSense FSS fine sun sensors, a NanoTorque GST-600 3-axis magnetorquer and a NanoSense M315 magnetometer.

GomSpace is able to deliver a standard platform without payload integration in 4 to 6 months after the order has been received. The 6U platform technical information is shown in table G.8.

Table G.8: GomSpace 6U CubeSat Platform technical information. Adapted from GomSpace Group AB [190].

Platform		Payload	
Size	6U	Payload Space	4U
Peak Power	12W	Av. Payload Power	Depends on orbit
Battery Capacity	77 Wh	Max. Payload Mass	4 kg to 6 kg
Platform Mass	5.6 kg	Payload Interfaces	I2C, UART, CAN bus
Platform lifetime	Designed 5 years	Power Bus	3.3V, 5V, 8V, 12V, 18V at 24V

G.6.2 Constellation Management

Satellite constellations need to be operated under shared control due to the complexity a large number of satellites in a constellation brings. GomSpace started to develop a system for constellation management in order to provide a service of in-orbit satellite operation. They see this service with big long-term potential. GomSpace states that the going rate for constellation services is about 20% of the satellite cost. Regarding a five-year CubeSat lifetime, the constellation management revenue potential equals the initial nanosatellite cost [191].

The product GomSpace is developing for constellation management is the Mega-Constellations Operations Platform (MCOP). It will be the result from a collaboration with the ESA to develop such platform at their Luxembourgian offices. The company claims that the MCOP service is designed from the ground up ready for constellations. It is a cost-effective solution for single satellites and large constellations and allows optimization by ground segment management. It presents a holistic approach in both space and ground segments and is under continuous development and improvement. The platform is divided in 3 groups [192].

- **Satellite Operations:** With the most modern softwares, automation, end-to-end integration and scalability, the MCOP can manage constellations and optimize business-wise. The automation is considered essential as it allows to focus on value improvement of the missions as well as near-instantaneous change in operational modes.
- **Network Management:** The MCOP connects the satellites, ground stations, data centres, wide area networks and end-user service delivery points to have them under control. Thus, network management of the MCOP requires and provides end-to-end assets monitoring, centralized configuration and redundancy management, autonomous network operations and fault recovery, and service quality management.
- **Mission Exploitation:** The MCOP platforms can help business to design and implement algorithms and business logics. This enables end-user service delivery and deployment from daily satellite operations. Some features prioritize the services that maximize revenues, data pre- and post-processing, archival, filtering and various data distribution models.

G.6.3 Additional Services

The additional services that GomSpace can offer to a customer are wide. They range from punctual mission services to full mission development and design. The services are [191]:

- **Payload and subsystems integration:** GomSpace offers platform integration of in-house payloads and subsystems, and payload junction development and customer integration.
- **Engineering support:** The company offers engineering support at any point of the mission, with special focus on the Launch and Early Orbit Phase (LEOP).
- **Ground Station support:** In addition to the constellation management, GomSpace offers ground station support by providing elements to the station or helping in its operation.
- **Launch services:** GomSpace offers launch services, specially to small missions, providing lower costs per launch for the customers. The launch service can extend from the payload fitting in the rocket to the in-orbit satellite configuration (LEOP).
- **Bureaucratic support:** GomSpace assists its clients with the satellite or constellation related paperwork and authorizations.

G.7 Production System

The GomSpace headquarter is located in Aalborg, Denmark. The majority of the products development occur there, including the assembly of integrated satellites as well as integration and testing of payloads and subsystems. GomSpace subsystems and payloads are composed by different electronic boards and mechanical parts supplied by local trusted suppliers. This ensures low cost, high quality and flexibility. However, the components are tested before being integrated into a GomSpace platform. The company aims to become more of a system integrator, in which they will have the possibility and skillset to manufacture complete satellites from payloads and subsystems build by GomSpace or other suppliers [191].

GomSpace aimed with an enlargement of their facilities to ramp-up their productions, going from low- to high-volume. According to the Danske Bank Commissioned Research, the increase in modularization and production automation together with the enlargement of the facilities augur a successful transition to the mentioned high-volumes production. GomSpace expects to be able to produce up to 1 CubeSat a day and start serial production [191].

G.7.1 GomSpace Methods to Reduce Development Time

GomSpace understands the role the Nanosatellites have in the space sector as secondary payloads. Accelerated schedules is common among their development. This forces the Nanosatellite companies like GomSpace to centre their project schedules in the development of subsystems, with little time left for system-level testing or higher-level functionality. Moreover, the essence of Nanosatellites is to compete with traditional satellites by being faster, cheaper, and better. Up to date, the faster and cheaper factors have been proved, but the better is still in jeopardy. Regarding astronomical and terrestrial imaging, and the radiation of kW of power, the CubeSats are still not better than traditional satellites. Thus, the better factor is measured with its Return of investment. For different collectives it has distinct meanings, going from faster and cheaper test cycles to a quick deploy and scale of the service, avoiding devaluation during the development phase. Emphasis is again put in the fast and cheap factors.

The GOMX-3 project served as a milestone for GomSpace to develop a production methodology that reduces the development time before delivery. The key factors that define this production methodology are summarized in 6 points exposed from section G.7.1.1 to G.7.1.6. It started because of a tight delivery schedule of less than a year. In addition, the ESA developed a list of requirements under the European Cooperation for Space Standardization (ECSS) for IOD. These requirements served as an efficient framework for managing the project and, since the GOMX-3 project, are a baseline for most turn-key delivery projects.

G.7.1.1 COTS Components

GomSpace utilizes standard COTS components to do more with less. The products that traditional satellites use are proven and highly tested, but they become obsolete quickly. The COTS components are usually used in CubeSats, allowing very compact and power efficient designs. They are tested only in temperature, vibration, and total radiation dose of up to 20 kRad. They guarantee a typical operative life of 2-3 years for CubeSats at LEO and VLEO.

G.7.1.2 Distributed architecture

A distributed CubeSat architecture in self-contained modules like the GOMX-3 is desired if a clear communication protocol between modules is defined. In this case, GomSpace uses the CubeSat Space Protocol (CSP) over the provided subsystem interfaces, like the Inter-Integrated Circuit (I2C). This brings 2 benefits; a reduction in subsystem interdependency and a standardization in the communication Interface Control Document (ICD).

The reduced subsystem inter-dependency is based on their self-contained nature, allowing them to be developed and tested independently. Trade-offs are subsystem internal, reducing the satellite-level engineering load and the external budget constraints to power, mass and bandwidth.

The standard ICD is used through the CSP. This protocol is a light-weighted network-layer with very small memory footprint. It has a simple API inspired in Berkeley sockets and supports connectionless and connection-oriented operations. The CSP can run on multiple physical layers, being easily ported to various architectures. It is used also for ground communications, meaning that from the point of view of a subsystem, there is no difference between communications to the On-Board Computer (OBC), other subsystems or the ground station.

G.7.1.3 Parameter System

The generic parameter system available in all GomSpace products and subsystems permits operators to perform safe in-flight configuration changes. This is a RAM and FRAM based system that allows robust non-volatile storage of parameters. It allows modification of configurations, calibrations and more actions without a software update. It stores and downlinks telemetry data and is integrated with the watchdog system.

The watchdog system resets and safely restores parameters, subsystems or the entire system in case of problems. They ensure the proper run of their firmware. At the subsystem level, if a problematic configuration is detected, an older and trusted configuration will be automatically reseted after a certain period of time. At the power supply level, a subsystem will be rebooted if an error is found in the networked communication bus. It reboots the entire satellite if no activity is recorded over 10 minutes. All the critical subsystems have a watchdog that can be reset from ground, as well as another that can reset the subsystem or the hardware automatically.

G.7.1.4 On-orbit Reprogramming

The CubeSats development time has been shortened due to tight schedules, affecting specially the mission software testing. Recognition of mission software errors at an early operation phase is crucial. The upload of new firmwares allows vital subsystems software reprogramming. GomSpace focuses the testing time on critical software elements as well as low level interfaces. High-level mission functionalities are left with lower testing priority. Their software upload system is also implemented with the watchdogs to reboot defective subsystem configurations.

G.7.1.5 On-Orbit Calibration

Attitude and control systems testing, and calibration of subsystems, like the ADCS, require tons of time and special facilities to simulate space conditions. The on-orbit calibration GomSpace implemented since the GOMX-3 project permits to focus the tests on basic hardware functionality and subsystems safe-mode. Some experiments are performed during LEOP, generating data for sensors and actuators calibration, and satellite parameter determination. The data is downlinked to start a calibration process, estimating parameters and subsequently adjusting accordingly on-ground and on-orbit settings.

G.7.1.6 In-the-loop Testing

This type of testing reduces test time during system development. A Simulink model is used with flight code in-the-loop, simulating sensor outputs. It accepts software-calculated actuator input and eventually ensures a smooth transition from simulation to flight. The standardized command interface that all GomSpace systems integrate helps the tests, being used in subsystem checkout, satellite testing and on-orbit operations.

G.7.2 Product Development

The GomSpace products are evolving by following a development plan for next generation communication Nanosatellites. It is driven by Nanosatellites being used as constellations routing devices and by future surveillance data extraction and compression. The platforms are continuously optimized through the company's IOD long-term technology development roadmap. The roadmap is sponsored by programs under ESA, EU Horizon 2020 and the Danish Innovation Fund. GomSpace development roadmap is directly affected by 4 market trends [193]:

- Making customers responsible space users:
  - De-orbit capabilities.
  - Orbit Awareness and Collision Avoidance.
- Implementing advanced space mission capabilities:
  - Formation flying.
  - Inter-plane and cross-plane satellite links.
  - In-space protocol and network management.
  - More powerful radios and modems.
  - More powerful on-board processing.
- Providing advanced platform capabilities:
  - Fast turnaround from idea conception to launch readiness.
  - Adaptable to different payload sizes, power and interfaces.
  - High duty cycle, by high power generation or low power consumption.
  - Advanced ADCS capabilities.
  - Autonomous operations capabilities on spacecrafts.
- Maturing mission assurance capabilities:
  - Operational lifetime of at least 5 years.
  - High availability of space infrastructure to ensure high availability of end-user services.
  - Cyber security.
  - Constellation Management with low operating expense.

The company evolution and development cover areas such as ISL, high performance propulsion technology, high gain antennas, new payloads and platforms. The radio solutions portfolio increased by adding to the VHF, UHF and S-band, the X-band and Ka/Ku band frequency ranges. This includes more powerful SDR processing components and high-power antennas.

The development of existing GomSpace's 1U, 2U, 3U and 6U CubeSat platforms continues, with the addition of the new 8U platform. It is already involved in some projects and maintains the modular GomSpace philosophy. Moreover, the company started to develop the 12U and 16U CubeSat structure platforms as the market evolves.

The power systems development includes a product range increase of the Modular Solar Panels and Deployable Solar Panels. Moreover, new versions of power supplies and battery packs are in progress. A sun-tracking Triple Deployable Solar Panels product range will soon be introduced.

Focusing on the 6U and 8U platforms, the propulsion systems development works on fast and low-cost series productions of standard propulsion modules. A new cost-effective hybrid propulsion system program will be launched soon, becoming a pioneer of its kind.

The development of software for constellation management and mission assurance is under way through GomSpace Luxembourg. The MCOP will be the basis of future satellite operations services for GomSpace as well as third party manufactured satellites. It recently passed the critical design review and the first operational release will occur soon.

Finally, several development activities are focused on processes and products improvement for deep space missions. The developed capabilities will be also implemented in LEO missions, improving their performance [193].

G.8 Operations

The company GomSpace is an active participant in research, IOD and partnership missions. While some of these operations have already finished, others are in progress or haven't even started yet. This section summarizes the most important operations for GomSpace. In most of them, the company has been part of a consortium.

G.8.1 **Past Operations**

The first operations presented are in the past. Their involved satellites have already re-entered the atmosphere, have failed, were lost or the program was cancelled.

G.8.1.1 GOMX-1

The GOMX-1 mission, also known as GATOSS, consisted on an experimental 2U CubeSat sponsored by the Danish Innovation Fund. GomSpace managed the project, with the Aalborg University, DSE Airport Solutions and Insero Software as partners. Its main objective was to demonstrate aircraft tracking from space based on ADS-B signals reception through a sensitive SDR. The satellite secondary mission was to perform EO using a NanoCam C1U colour camera.

The GOMX-1 satellite was launched in November 21, 2013 on a Dnepr rocket from Dombarovsky, Russia. It was successfully deployed and operative, with only a stability issue. The satellite residual dipole moment was higher than expected, so the CubeSat was stable only on 2 axes. Thus, the antenna wasn't always pointing downwards. The data from the primary payload received intermediately the desired aircraft signals with a better-than-expected helical antenna link budget. The ADS-B payload continued working properly until May 7, 2014. Due to an increased power draw the payload was power cycled and stopped responding. The satellite is still operational, but only the secondary payload is available for experiments. GomSpace uses the CubeSat nowadays to characterize the radiation effects on their subsystems. They declared this mission as successful. The company stated that the GOMX-1 mission showed how CubeSats can contribute to develop new space-based services such as air traffic monitoring.

The GOMX-1 is a standard 2U CubeSat that weighs about 2.66kg. It incorporates 4 deployable UHF antennas for communications and a deployable helical antenna for ADS-B signal reception. About half CubeSat is dedicated to subsystems, while the other half to payloads. A key feature of the modular architecture is the CubeSat Space Protocol (CSP). This service-oriented network protocol is implemented in all subsystems and ground segment. The subsystems become autonomous nodes able to access and command resources available in the network. The satellite components are described below.

- **NanoMind A712:** OBC with up to 2 GB of data storage for all subsystems. Its main objective is to process the ADCS subsystem as well as to interface with all platform sensors and actuators. Its flexible software is used to support the mission.
- **NanoPower EPS:** This subsystem is formed by the NanoPower P110 Solar Panels and the NanoPower P31u power supply with batteries. The triple junction cells and the power supply with lithium-ion batteries were already explained in section G.5.2 Power Systems.
- **NanoCom U482C:** This half-duplex UHF transceiver composes the communications system. It operates in UHF from 435 MHz to 438 MHz. The NanoCom U482C includes baseband processing and uses I2C platform communication. The space link reliability is increased and improved using Forward Error Correction and Reed-Solomon coding.

- **Attitude Control and Determination System:** The magnetically actuated 3-axis control system also incorporates sun sensors. Using its magnetic coils, the device can provide nadir and internal pointing in its modes with an accuracy of 10°.
- **SDR (Payload):** The SDR main objective was to receive ADS-B signals from aircrafts. These signals are a set of data packages transmitted periodically from the Mode-S transponder of the aircrafts at 1,090MHz. It contains the aircraft position, altitude, ID and intent. The deployable helical antenna receives the signal with 10dB gain at 1,090MHz. The receiver is then composed by the RF front-end, the Field-Programmable Gate Array (FPGA) and finally the Micro-controller unit. The first one, with big sensitivity, amplifies and down-converts the signal. The second one, reconfigurable from Earth, samples the down-converted signals and run the decoding algorithms. The final element stores the received data and delivers it to the CSP network if there is opportunity for downlink.
- **NanoCam C1U (Payload):** The secondary payload of the GOMX-1 is a CMOS colour camera for EO experiments with a resolution of 35 m at 600 km orbit altitude.

G.8.1.2 GOMX-2

The GOMX-2 was a project lead by GomSpace with the intention to perform IOD of technologies. The satellite was a 2U CubeSat with similar weight and architecture than its predecessor GOMX-1. The main mission objectives were to test de-orbit systems, to perform optical communications experiments and to evaluate new generation high-speed UHF transceiver and SDR receiver. the first 2 objectives were in collaboration with the Aalborg University and the National University of Singapore respectively. Its downlink data frequency was supposed to be 437.25 MHz. The CubeSat was launched on October 28, 2014, on the Cygnus CRS-3 cargo vehicle. It was supposed to reach the ISS in order to be deployed from the Japanese airlock. Its orbit should have been of 400 km and an inclination of 51.6°. However, shortly after the rocket lift off it exploded. The GOMX-2 was successfully recovered undamaged and is now exposed at the Science Center Singapore.

G.8.1.3 GOMX-3

The GOMX-3 was a GOMX IOD project lead by GomSpace and under the IOD section of the General Support Technology Program from ESA. The project also incorporated the Aalborg University and Syrlinks, a French company funded by the French space agency (Centre National d'Études Spatiales (CNES)). It is a successor of the GOMX-1 and GOMX-2 CubeSats. The mission main objective was to demonstrate advanced satellite pointing while receiving both L-band and ADS-B signals. However, in practice, the objective was split in 3 goals:

- To demonstrate three-axis pointing to an accuracy of 2 degrees or less.
- To provide aircraft position measurements via space-based ADS-B reception.
- To demonstrate new capabilities for SDR payloads aboard Nanosatellite platforms.

After three months in orbit, the objectives were achieved. The attitude control showed 1 degree pointing accuracy with up to 7 attitude changes per orbit and could track targets. The SATCOM spot-beam was characterized, and the spectrum monitored in L-band for the SDR. Finally, successful worldwide ADS-B aircraft tracking was achieved. Moreover, the Syrlinks high-speed X-band downlink capability was demonstrated with 3MBps downlink to ESA and CNES ground stations in Kourou and Toulouse respectively [156].

One of the most outstanding features of GOMX-3 development was its quickness. The CubeSat was designed, integrated and launched in less than 1 year. This was a project time frame constraint and was solved thanks to the collaboration between GomSpace and ESA. The latter developed a tailored European Cooperation for Space Standardization (ECSS) intended for IOD CubeSats in LEO missions. It reduced the number of full requirements contained in a full ECSS standard, converting them in applicable, guideline or not applicable. In addition, GomSpace created new methods to reduce development time by focusing on payload and subsystem-level, development and testing (see section G.7 for further method details).

The GOMX-3 was launched from Japan on August 19, 2015 on-board the HTV-5 rocket. It arrived at the ISS to be deployed from a Nanoracks deployer on October 5, 2015. The satellite transmitted the first beacon to the Aalborg ground station with healthy telemetry, strong beacons, full battery, and de-tumbled attitude. It passes about 5 times a day over the ground station with an average pass length of 7.4min. The first 37 minutes of contact were determined to confirm the satellite healthiness in power, communications and attitude determination & control. Then the payloads were checked out with similar successful results. They include the advanced ADCS, the ADS-B receiver, the NanoCom SDR and the Syrlinks EWC27 X-band transmitter.

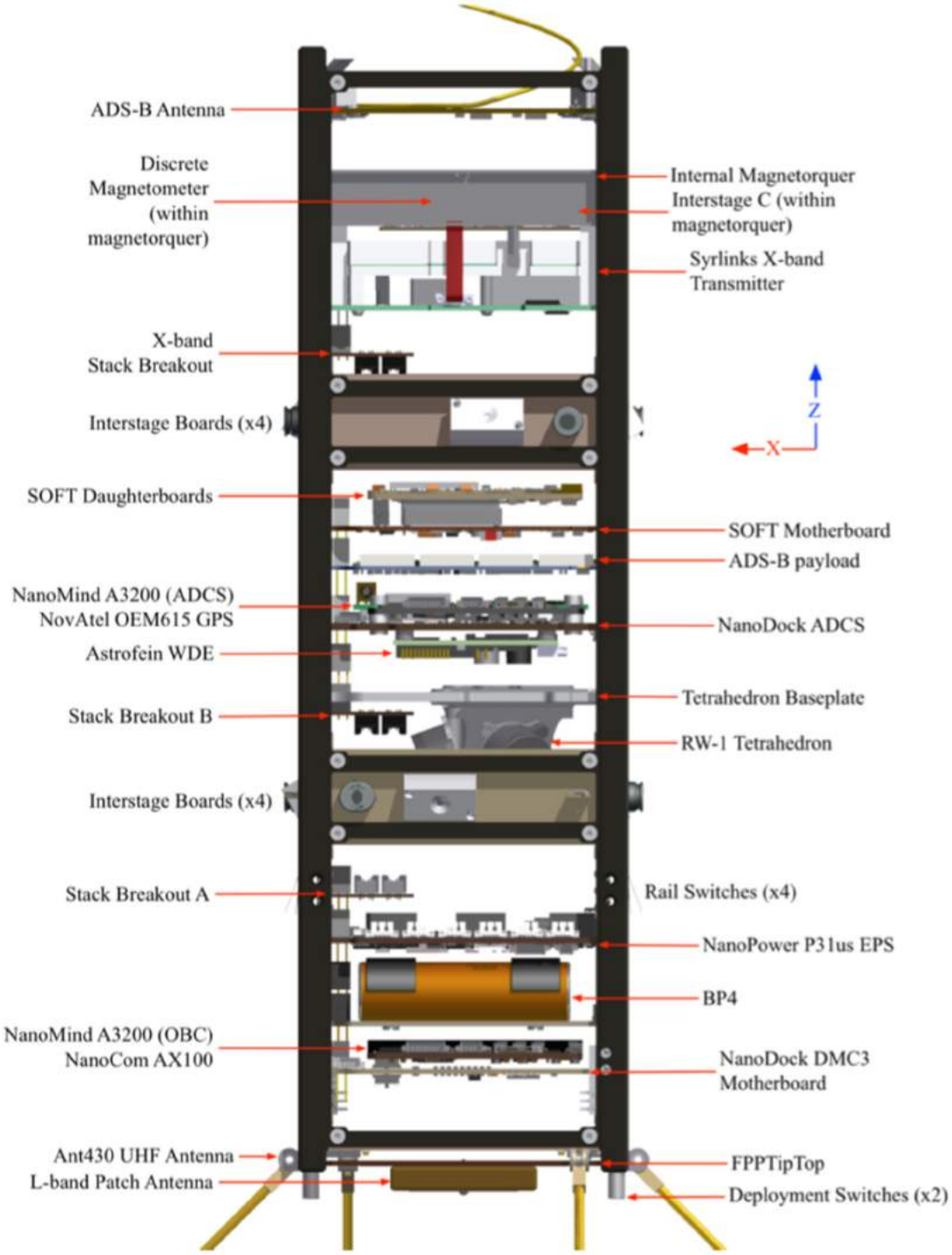

Figure G.4: GomSpace-3 internal layout. Image credit: Gerhardt et al].

The 3U CubeSat incorporates may COTS components in its bus. The bottom 1U is used for satellite subsystems, the middle 1U for the ADCS system, the NanoCom SDR and the ADS-B receiver, and the upper 1U for the X-band transmitter and further ADCS support hardware. Figure G.4 shows the internal layout of the GOMX-3. The communications between bus components, as in the GOMX-1, is executed through CSP. The most important components are described below.

- **NanoPower P31us:** EPS power supply without batteries (see section G.5.2 Power Systems).
- **NanoPower BP4:** EPS battery pack with 4 Li-Ion series cells (see section G.5.2 Power Systems).
- **NanoMind A3200 OBC:** Mission OBC that stores mission-specific commands and non-ADCS telemetry for downlink (see section G.5.4.1 NanoMind A3200).
- **NanoCom AX100:** Primary RF UHF communications method. In-orbit adjustable in frequency, bitrates and data encapsulation (see section G.5.3.1 Space Segment).
- **NanoMind A3200 ADCS:** OBC dedicated only to ADCS operations. Filters sensors data inputs, applies control and commands actuators for stability (see section G.5.4.1 NanoMind A3200).
- **NovAtel OEM615 GNSS:** GNSS receiver compatible with GPS and GALILEO.
- **AstroFein RW-1:** 4 CubeSat reaction wheels assembled in a tetrahedron and controlled by the AstroFein WDE driver board.
- **NanoUtil Interstages:** 9 small PCBs that collect ADCS data from sensors and control the antennas deployment. They house fine sun sensors with 2-axis sun vector measurement.
- **NanoCom Ant430:** 4 canted, deployable, turnstile and omnidirectional UHF antennas (see section G.5.3.1 Space Segment).

The GOMX-3 payloads that have already been mentioned are described below.

- **NanoCom ADS-B:** Updated ADS-B receiver version in hardware and software from the GOMX-1. More resilient to single event upsets, it collects data from the deployable helix antenna on the body +Z face (see section G.5.1.1 Aircraft Tracking ADS-B).
- **NanoCom SDR (SOFT):** SDR based on the Xilinx Zynq Z7030 FPGA. It can be augmented with up to 3 Front End Modules to interface with multiple antennas. The GOMX-3 uses an L-band patch antenna on its -Z face (see section G.5.1.3 Software Defined Radio (SDR)).
- **Syrlinks EWC27:** Syrlinks X-band transmitter capable of bit rates up to 100 Mbit. However, only 3 Mbit are downlinked from a GOMX-3 X-band patch antenna on its +Y face.

The Nanosatellite working life was extended about 6 months until its re-entry on October 10, 2016. In addition to the accomplished mission objectives, new successes were achieved. The satellite life was extended thanks to new ADCS algorithms that reduced the aerodynamic drag. The near real-time ADS-B data was integrated into the Flightradar24 interface in collaboration with Airbus Defence and Space. It provided aircraft live-tracking over the North-Atlantic. Finally, in association with the UK Met Office and the ESA, the recorded ADS-B data was used to obtain aircraft-measured wind data. The project gave GomSpace 4 important lessons to learn.

- The invaluable importance of a model. They could reduce the troubleshooting time and risk of fixing an on-orbit CubeSat by attempting it first on a model.
- The value of reconfigurability. The tight schedule didn’t allow enough time for testing. On-orbit calibration of the ADS-B and X-band downlink software debugging was crucial.
- The usefulness of an easy reviewable telemetry. The easier it is to review satellite data; the quicker problems and solutions can be found.
- The helpfulness of automatic data collection. With a ground station autopilot to collect data, GomSpace addressed the long-term effects of multiple satellite passes and their possibility to occur during non-working hours.

G.8.1.4 TeSeR

The Technology for Self Removal of Spacecraft project was part of the EU Horizon 2020 research and innovation program. It aimed to reduce the risk of spacecraft colliding with space debris. The project started in 2016 and lasted until early 2019, with an overall budget of EUR 2.84M. Airbus DS GmbH was the coordinator of an 11-members consortium that included GomSpace. The project proposed a cost-efficient prototype of a highly reliable Post-Mission-Disposal module. This independent module should be carried by future spacecrafts to ensure proper disposal after ending their service lifetime. The main project objective is to develop the module up to a tested on-ground prototype. GomSpace role is to develop the satellite bus interface and the system responsible for safe and timely re-entry module actuation [194].

G.8.1.5 SAGAS

The Satellite Augmented Global Aircraft Surveillance feasibility study was performed by the ESA and 6 other companies, including Airbus Defence & Space (UK) and GomSpace. It aimed to develop service propositions for ADS-B technology and its augmentation, meeting user needs and creating new enhanced operations opportunities and business benefits. The study successfully finalized in September 2018 with a list of candidate-services based on ADS-B integrated applications for global aircraft surveillance [195].

G.8.1.6 OPS-SAT

The OPS-SAT is a 3U CubeSat developed by the ESA. It aims to be a flying laboratory, testing and validating new techniques in mission control and on-board systems. The idea behind the OPS-SAT project is to design a low-cost, rock-solid safe and robust CubeSat resistant to malfunctions in testing. Almost every aspect of the satellite's on-board software will be changed on-the-fly without major mission risks. GomSpace was meant to deliver the core satellite platform. However, they have lost importance and involvement in the project.

G.8.2 Current Operations

At the moment GomSpace is involved in many missions as part of a consortium, being only a member or the group leader.

G.8.2.1 GOMX-4

The GOMX-4 is an IOD mission of a constellation of 2 6U CubeSats based on the successful GOMX-3 project. The GOMX-4A is sponsored by the Danish Defense Acquisition and Logistics Organization while the GOMX-4B is funded by the ESA under the IOD program. The main objective of the mission is to demonstrate Inter-Satellite Link (ISL) communication between constellation satellites. While both satellites fly at Sun Synchronous orbits at about 500 km, one CubeSat captures data from a targeted region and then transmits it to the second one. The distance between the satellites should be from 200 km to 4,500 km. Finally, the receiver satellite downlinks the data to the main ground station in Aalborg. Individually, the satellites have other mission objectives. The GOMX-4A intends to monitor Greenland and the Arctic region by capturing images, AIS ships data and ADS-B airplanes data. The GOMX-4B seeks to demonstrate orbit control manoeuvres based on cold gas propulsion, hyperspectral imagery, high accuracy attitude determination and COTS behaviour analysis in space.

Both satellites were launched on February 2, 2018 on board of the Long March 2D-Y13. They were deployed from the PSL-P. The first 3 operational weeks were used to check optimum subsystems behaviour. The following 4 weeks were used for a similar task with the payloads. Due to a difference in deploying time, the satellite orbits were slightly different. An increased drift between them was noticed. Thus, the propulsion system in the GOMX-4B and differential drag surfaces in both CubeSats were used to correct the orbits. The Nanosatellites were flown in tandem, eventually increasing the distance between them up to 4,500 km in order to determine the ISL limits.

The satellites have a 6U CubeSat structure with similar platform components. However, their payloads are mostly different. The common subsystems are the **NanoMind A3200** OBC, the EPS **NanoPower P60**, the ADCS and the two UHF **NanoCom AX100** and S-band **NanoCom SR2000** ground communication links. The NanoMind A3200 and the NanoCom AX100 subsystems were already on-board the GOMX-3 satellite. However, the rest bring relevant platform updates. The upgraded version of the ADCS uses external gyro sensor, powerful reaction wheels and different star tracker technologies in addition to the successful previous missions' components. More information about the subsystems can be found in section G.5 Satellite Payloads and Subsystems.

The GOMX-4A hosts already flight proven AIS and ADS-B receiver payloads. It incorporates the 3 Mpx **NanoCam C1U** to monitor regions of interest like Greenland and the Arctic. As its twin CubeSat, ISL components were installed. They include 2 patch antennas in every end of a 2U unit and a GomSpace SDR. The last one is capable of using 2 innovative modulation techniques for short and long distances. Some dummy masses were included to equalize the mass difference with the GOMX-4B, facilitating dynamics and behaviours.

The GOMX-4B incorporates the GomSpace cold-gas **NanoProp 6U Propulsion** module as principal payload to demonstrate orbit control manoeuvres (see section G.5.5.2 Propulsion Systems). The GOMX-4B also has identical ISL payload components than the GOMX-4A. As the duration of this satellite payload demonstration phase should last about 6 months, an external transceiver to the ISL SDR is incorporated to acquire ADS-B data for a future commercial GomSpace phase.

Moreover, this CubeSat hosts 3 other external technology demonstration payloads. The Cosine **HyperScout** camera is a miniaturized hyperspectral imager with an on-board real time data processing unit. It provides a 70m ground sampling distance at 500km using its three mirror anastigmat telescope. The **Chimera** electronics board from ESA incorporates 12 separate computer flash memories whose performance in space is being monitored by a space-qualified chip. This cheap COTS board is tested under a radiative space environment. A **Star Tracker** from ISIS is tested to provide high accuracy in attitude determination [160].

By the end of 2018, the GOMX-4 mission already completed successfully its mission objectives. The two satellites are still operative, with an expected lifetime between 3 and 5 years. They will be operated by the GomSpace Luxembourg subsidiary in charge of mission exploitation [160]. While executing the mission, new challenges raised. They were addressed in order to develop up-scaled constellations in future missions:

- The verification processes were optimized, reducing development cost and time by using the Proto-Flight Model approach.
- Orbital data was inaccurate during LEOP. An autonomous GPS implementation must be included, involving higher complexity and power consumption at LEOP.
- Communications to a shared ground station at same frequencies by both CubeSats involved challenges as no simultaneity was possible. Using different frequencies or coordinating the transferred data between satellites would minimize the operations waiting time.
- Automation of non-critical data communication would reduce late-night downlink difficulties. These ground station functions are under development since the GOMX-3.
- For future commercial missions, operations procedures and training should be settled, including telecommand, telemetry actions and a data delivery interface for clients.

G.8.2.2 RACE

The Rendezvous Autonomous CubeSats Experiment is a mission under ESA's IOD program. The project aims to develop new technologies for CubeSats in order to perform close proximity operations, including in orbit rendezvous and automatic docking. The mission consists of 2 6U CubeSats that will perform close flyby around uncooperative bodies. GomSpace is the leading company of the mission consortium, delivering the 2 6U CubeSats. The other members are GMV, providing the guidance, navigation and control systems, Almatech, working on the docking mechanism, and Micros, delivering the visual navigation camera.

G.8.2.3 DISCOVERER

The DISCOVERER project is run by a consortium of 8 partners in which GomSpace participates. It is funded by the EU Horizon 2020 program with EUR 5.7M. It aims to find new technologies in order to drastically redesign EO platforms, making them sustainable operative at much lower altitudes. The targeted satellites altitude is at VLEO, providing more advantages than drawbacks.

The aerodynamic challenge of the gas-surface interaction with atomic oxygen will be mitigated with the identification, development and characterization of new low drag materials. A facility to study the aerodynamic properties of these materials will be created. The Rarefied Orbital Aerodynamics Research Facility will count with a continuous flow of hyperthermal atomic oxygen and a flow field diagnostic equipment in an ultra-high vacuum chamber.

In addition, a test spacecraft will validate the findings at VLEO. The Satellite for Orbital Aerodynamics Research is a 3U CubeSat that will be launched in 2020. It will have 2 payloads to investigate interactions between different materials and the orbit atmosphere. The steerable fins containing the materials can vary their geometry and angles of incidence. The satellite mission will be to demonstrate aerodynamic attitude and orbit control manoeuvres. This satellite incorporates an Ion and Neutral Mass Spectrometer that accurately measures the flow composition, density and the thermosphere wind velocity. GomSpace is the leader of the work package that develops the IOD CubeSat.

Another way to compensate the aerodynamic drag is by compensating it with a propulsion system. The project aims to design, build, and test an atmosphere-breathing electric propulsion system that uses the orbit atmosphere gas as propellant for an electric thruster. The ABEP system is used to maintain the VLEO orbit, compensating the aerodynamic drag, for long time without need of carrying additional propellant on-board. Moreover, it can provide a certain extent of control over the orbital parameters as well. Active aerodynamic control manoeuvres will be designed and tested in the IOD CubeSat, aiming to exploit the available aerodynamic forces and torques.

The research in spacecraft atomic oxygen resistance, electric propulsion, control methods, aerodynamic characterization and materials are fundamental for the project. The project is highly multidisciplinary, involving from surface chemistry to control engineering, among others. It intends to develop key technologies from concept (TRL 1-2), through proof-of-concept, and on to validation (TRL 4-5). Discoverer will eventually define roadmaps that will serve as guidelines to commercialize these new technologies, making EO at VLEO become a reality.

G.8.2.4 DOC

The Demise Observation Capsule project is run by a consortium of 7 companies, led by S[&]T and in close cooperation with the ESA. The objective is to develop a capsule that measures a re-entry process. It will serve to study the rocket upper-stage trajectory, footprint and disintegration during the atmosphere re-entry. The capsule starts measuring after the final separation stage, collecting velocity, acceleration, GPS position, pressure and temperature data. A camera also records the entire descent. GomSpace contributes to the project by designing and delivering the capsule avionics and sensors [196].

G.8.3 Future Operations

GomSpace has already signed contracts for new projects. Here are the most significant.

G.8.3.1 GOMX-5

GomSpace announced in December 2018 a new collaboration with ESA for the development of a new GOMX IOD satellite mission, the GOMX-5. This mission will aim to demonstrate new Nanosatellite constellation capabilities regarding high speed communication links and high levels of manoeuvrability. It will consist on 2 12U CubeSats with similar components than the GOMX-4 but increased power handling and reliability. With an expected launch scheduled for 2021, the project development is only guaranteed for the initial phase during 2019. This is due to the current contract between GomSpace and the ESA that only covers EUR 300K, leaving the subsequent additional contracts subjected to the progress of the project. Some payloads and subsystems that the 2 CubeSats will host have been announced [197].

- A propulsion system developed by ThrustMe, ExoTrails and GomSpace Sweden.
- Two X-Band high gain reflect array antennas developed by Ticra.
- Miniaturized and improved star trackers developed by EICAS.
- High accuracy GNSS receivers developed by Deimos and GMV.
- Powerful and radiation tolerant OBCs developed by Cobham Gaisler AB and LIRMM.
- State-of-the-art radiation monitors developed by Surrey Space Center and the Czech Technical University.
- A lightweight Earth observation imagery developed by Tartu Observatory.
- AI on spacecraft developed by AIKO.
- A Ka-Band ISL developed by GomSpace.

G.8.3.2 A&M

GomSpace is the sole deliverer of a full space-based business infrastructure to Aerial & Maritime Ltd. (A&M). Due to GomSpace's partial ownership of A&M, this project can be considered as almost theirs. The objective of the initial 8 3U CubeSats will be to track aviation and maritime traffic between 37° north and south of the equator. Thus, each satellite, the Starlings 1 to 8, will be equipped with an ADS-B and an AIS receivers. The launch of these CubeSats is expected to occur during 2019 on-board the Virgin Orbit's LauncherOne.

GomSpace is responsible for the satellite design, configuration, production and testing of the 3U CubeSats. They also provide the launch service to a 12° near equatorial orbit, the installation of the ground segment, training, the CubeSats commissioning and operational support [198].

G.8.3.3 M-ARGO

The Miniaturized Asteroid Remote Geophysical Observer (M-ARGO) mission will develop the first ever CubeSat for asteroid rendezvous and close proximity resources identification. The latter includes the characterization of the asteroid physical properties like its shape, surface or mass. It also aims to assess the potential for resource exploitation, checking the asteroid composition and hydration. GomSpace signed a EUR 400K contract to develop the Phase A preliminary design of the mission, spacecraft and implementation planning. The 12U CubeSat will host state-of-the-art miniaturized payloads for deep-space IOD in communication, instrumentation, electric propulsion and operational autonomy. Some payloads like a Multi-Spectral Imager and a LASER Altimeter have already been announced [199].

The data collected during 6 months of measurements will return to the Earth using a X-band (8.4GHz) transponder and a high-gain antenna array. The M-ARGO could perform an alternative mission, becoming a space weather observatory at the Sun–Earth L5 Lagrange Point. For that it needs a radiation monitor and a boom-based magnetometer instrument.

The launch is expected in 2023, following the development work additional contracts of next phases. GomSpace will develop the project in its Luxembourgian subsidiary. The Politecnico di Milano will support GomSpace with deep space mission analysis and navigation of low thrust trajectories associated with electric propulsion [199].

G.9 Partnerships

Many companies cooperate with GomSpace in order to achieve similar objectives. The partnerships that they have developed is crucial for the company's growth. The most important can be distributed into 3 groups depending on their nature and purposes. They are the partnerships created to develop IOD projects, the spin-off strategy partnerships and the customer companies' partnerships to develop large CubeSat constellations.

G.9.1 IOD Partnerships

The most characteristic In Orbit Demonstration (IOD) GomSpace missions are under the GOMX program. They were possible thanks to the collaboration of GomSpace with partners. Their involvement in the projects could go from monetary investments to technical support and collaboration. The most important partners regarding these aspects are bellow.

G.9.1.1 The European Space Agency

The European Space Agency is probably the biggest GomSpace partner. Their first cooperation dates from 2014 with the GOMX-3 CubeSat mission. They contributed to the project actively, providing financial investments, ground station capabilities and technical assistance. The successful cooperation lead to the GOMX-4 project. The ESA was mostly involved in the GOMX-4B CubeSats. Both parts have announced a new collaboration for the GOMX-5 mission development. GomSpace participates with the ESA in other projects like the SAGAS, OPS-SAT, RACE, DOC or M-ARGO (see section G.8 Operations). They all have different objectives but are Nanosatellite-related. In addition, both parties sealed a contract to develop the MCOP project. It aims to offer constellation operations services to small satellites.

G.9.1.2 The Aalborg University

The Aalborg University has worked hand by hand with GomSpace in many projects like the IOD GOMX. They contribute on satellite payload development and other technical issues. GomSpace provides internships and working opportunities to the university students due to their close relation. It is based on the proximity of both entities and on the university being the alma mater of the company founders.

G.9.1.3 The Danish Defense

The Danish Defense has partnered with GomSpace to support them financially and technically on the GOMX-4A development. The GOMX-4 mission CubeSat aims to monitor Greenland and the Arctic region by capturing images, AIS ships data and ADS-B airplanes data. This partnership is very important for GomSpace as it is the first with a governmental entity.

G.9.2 Spin-off Strategy Partnerships

A Spin-off is an operational strategy that a company uses to create a new separate business subsidiary. The spin-off company is supposedly more valuable than as part of a large business. It takes assets, employees, product lines or technologies from the parent company in exchange of an amount of money. Eventually, as the subsidiary grows, GomSpace intends to dilute its ownership percentage to transform the spin-off interests into good customer relationships [200].

G.9.2.1 Aerial & Maritime Ltd. (A&M)

The first and most valuable GomSpace spin-off partnership is with Aerial & Maritime Ltd. Established in 2015, A&M aims to track aircrafts and ships to predict their paths using in-orbit ADS-B and AIS technologies respectively. They started with a GomSpace-developed 8 satellites constellation for equatorial coverage, the Starling 1-8. This contract had a USD 10M value. The next company step is to launch a same-purpose global constellation that would require about 80 CubeSats. This new project is estimated to be worth about USD 100M. GomSpace and A&M signed a MoU in June 2018 to eventually sign an order contract. GomSpace currently owns 39% of A&M shares, while the rest is distributed between private equity and the Danish Government through the Investment Fund for

Developing Countries. The sales and revenues generated from A&M represent a big part of the company totals. [201].

G.9.2.2 Singapore Technologies Electronics

Aiming to obtain constant communications between aircrafts and airports, GomSpace started a research collaboration with the CAAS and the publicly listed Singapore Technologies Electronics. They could reduce the aircraft safety distances from 80 to 5 NM. It is believed by the Danske Bank analysts Stjerngren and Elvind [201] that GomSpace would likely develop a joint-venture structure relationship with the latter company similar to A&M. GomSpace will most likely be the supplier of an eventual commercialized solution resulting from the research.

G.9.3 Large Constellation Partnerships

The majority of the sales and revenues of GomSpace are generated by 3 large customers; A&M, AISTECH Space S.L. and Sky and Space Global (UK) Ltd. The different agreements with these customers share an objective to develop large EO satellite constellations [202].

G.9.3.1 AISTECH

GomSpace sealed a framework agreement in 2017 with the Spanish company AISTECH for a purchase of 100 CubeSats until December 31st, 2021. The total value of this agreement was estimated in EUR 12.5M. However, there are no purchase commitments in the agreement. Payments are placed every time there is a purchase order. GomSpace has receiver two orders so far for a total of 10 Nanosatellites worth EUR 1.24M.

G.9.3.2 Sky and Space Global

In 2017 Sky and Space Global and GomSpace entered a procurement agreement to develop and deliver 200 Peals constellation CubeSats. The initial contract, with a EUR 64.5M value, was set to deliver the satellites over 4 years. GomSpace delivered 3 3U Nanosatellites corresponding to a previous IOD constellation, the Diamonds. They received EUR 4.28M for it and the start of the Pearls. However, by the end of 2018 GomSpace didn’t receive the expected overdue invoice payments of SEK 33.317M, affecting negatively the Company’s economy. Eventually, and after Sky and Space Global cash flow situation assessment, GomSpace received an amount of SEK 20.819M corresponding to the Critical Design Review invoice [201]

Finally, GomSpace and Sky and Space Global updated their situation with a new agreement to design 6U Cubesats (“6U Agreement”) and agreeing to change the original Pearls agreement. In the 6U Agreement, GomSpace will deliver a batch of 8 6U CubeSats by Q1 2020 worth EUR 5.3M. A second optional batch of 8 Nanosatellites would be delivered in H1 2020 and is worth EUR 3.8M. The CubeSats will use assets developed under the Pearls Agreement. The negotiations to modify the original 2017 agreement were supposed to finalize before mid-June. However, both companies agreed to extend the negotiations until August 31st, 2019 [201].

G.10 Financial Status and Risks

This chapter is divided between GomSpace financial performance and risks. Both topics are closely related as many of the risks the company is exposed to are financial. The monetary amounts are presented in SEK.

G.10.1 **Sky and Space Global**

In order to illustrate the financial performance of GomSpace, tables 5.9 and 5.10 are presented. They respectively show the financial key figures and ratios. The last available interim report indicates first quarter results for 2019 (Q1 2019) [201]. The information is presented in 2 different sets. The first 2 data columns show the first quarter values of 2019 and 2018, while the rest present the yearly results from 2018 to 2014.

The net revenue and gross profit have decreased in Q1 2019 compared to the same 2018 period by 21% and 97% respectively. The gross margin also decreased from 35% in Q1 2018 to 1% in Q1 2019. The operating profit, in this case loss, increased in an 83%, with the operating margin going from -40% to -92%. Thus, the result for the Q1 2019 period was a net loss of SEK -30.184M. This represents 118% more than in Q1 2018, with a net margin decreasing from -37% to -101%. The tendency is highly influenced by the resources overcapacity resulting from putting on hold the Sky and Space Global project and lower-than-expected order intakes.

The yearly tendencies of these key figures and ratios is similar. Even though the revenues have increased since 2014, the gross, operating and period profits have decreased. It is observed in decreases of the gross, operating and net margins. The income statement evolution in figure G.5 illustrates the tendencies of these key figures and ratios in recent years. Last GomSpace long term goals aimed to obtain sales (Net Revenues) above SEK 1.5B by 2023 and a medium-term target gross margin over 50%. The current revenues tendency indicates that the goal is far. The yearly increase is not sufficient and the Q1 2019 results show a recession. More concerning is the evolution of the gross margin. It hasn't stopped to decrease its value, positioning at half the target (25%) at the end of 2018 and at a minimum of 1% by Q1 2019.

Investments in Property, Plant and Equipment (PPE) are related to new production equipment and facilities, increasing constantly since 2014. The investments in intangible assets account mostly for in-house development projects from the portfolio or improvements in constellations management. They have experienced a yearly increase of about 50% in recent years. However, the Q1 2019 saw less invested money than Q1 2018 in both categories.

Table G.9: GomSpace Group AB financial key figures in Thousands of SEK. Adapted from GomSpace Group AB [203].

Key Figure	Q1 2019	Q1 2018	2018	2017	2016	2015	2014
Net Revenue	29,877	37,738	153,384	96,405	54,142	34,087	26,645
Gross Profit	446	13,171	8,549	26,884	25,201	17,195	11,029
Operating Profit (loss)	-27,630	-15,093	-116,601	-67,610	-14,510	-2,357	1,762
Profit Share from Associates	-805	-111	-2,112	4,591	21,386	-	-
Net Financial Items	-1,150	-1,368	-4,098	-3,496	-1,389	-766	-178
Profit (loss) before Tax	-29,585	-16,572	-122,811	-66,515	5,487	-3,123	1,584

Profit (loss) for the Period	-30,184	-13,820	-112,498	-53,989	8,981	-2,369	1,224
Intangible Assets Invest.	10,715	13,811	65,477	38,908	21,848	5,489	747
PPE Invest	3,304	4,283	25,349	18,500	6,447	543	528
Total Assets	603,112	414,341	608,542	313,069	209,093	30,067	19,051
Equity	414,521	296,096	441,843	185,315	146,106	13,826	7,721
Total Liabilities	188,591	118,245	166,699	127,754	62,987	16,251	11,330
Working Capital	-5,024	9,205	6,010	23,606	-7,399	-13,821	-4,580

The associates profit share is a share result from GomSpace partially owned Aerial & Maritime Ltd. (A&M). The A&M results have turned from profit to loss over the years. The net financial items have negatively increased along years, resulting in a negative effect on profit. However, during Q1 2019 they decreased compared to Q1 2018. They are mainly due to interest on debt and leasing liabilities.

The total shareholders' equity at the end of the periods has constantly increased. However, this is mostly due to the constant share issues. A good comparison is between the end of 2018 and Q1 2019, where the number of shares is the same but there is a loss of SEK 27.33M in equity. The return on equity has decreased along the years as well as from Q1 2018 to Q1 2019. The liabilities have constantly increased in accordance to the company will for expansion, but at lower levels than equity.

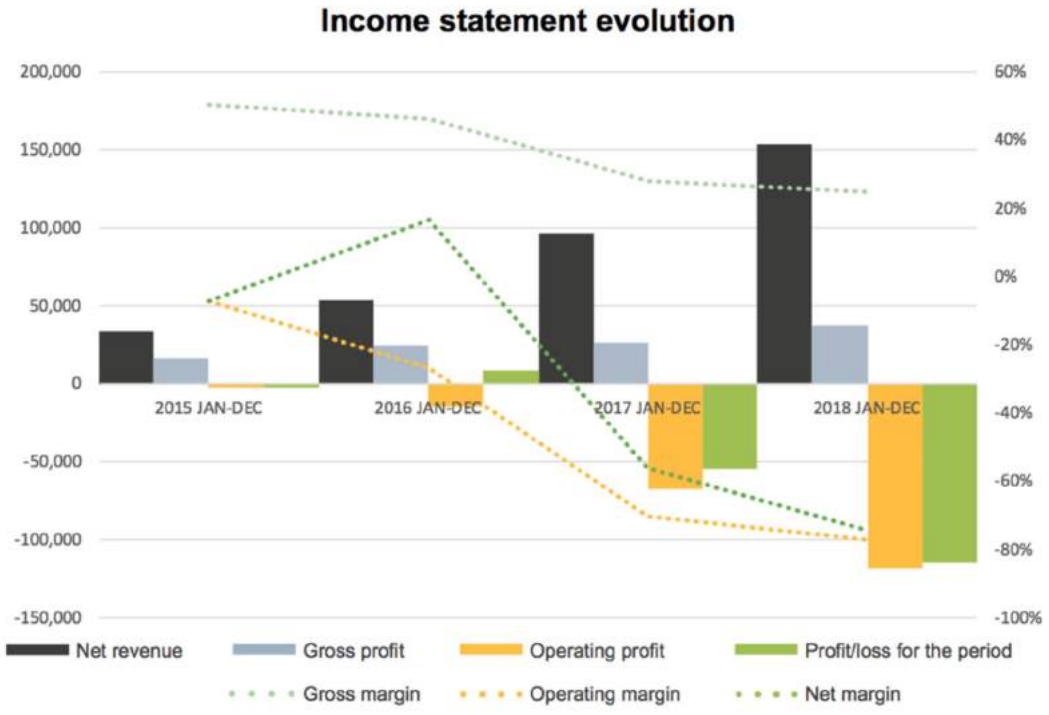

Figure G.5: Income Statement Evolution from 2015 to 2018 in Thousands of SEK. Adapted from GomSpace Group AB [203].

Table G.10: GomSpace Group AB financial ratios. Adapted from GomSpace Group AB [203].

Ratio	Q1 2019	Q1 2018	2018	2017	2016	2015	2014
Gross Margin	1%	35%	25%	28%	47%	50%	41%
Operating Margin	-92%	-40%	-76%	-70%	-27%	-7%	7%
Net Margin	-101%	-37%	-73%	-56%	17%	-7%	5%
Invest. Capital Return	-5%	-3%	-18%	-17%	4%	-8%	6%
Equity Return	-8%	-6%	-36%	-33%	13%	-22%	18%
Equity Ratio	69%	71%	73%	59%	70%	46%	41%
Basic earnings per share (SEK)	-0.58	-0.52	-3.93	-2.09	0.62	-	-
Diluted earnings per share (SEK)	-0.58	-0.51	-3.93	-2.08	0.62	-0.17	0.09
N. of Shares by end of period	52.275M	28.341M	52.275M	26.257M	24.507M	-	-

Regarding the previous two key figures, the total assets of the company have increased exponentially over the years. The return on invested capital has decreased in the last years, as well as in Q1 2019 compared to Q1 2018. On the other hand, the equity ratio has established a value around the 70% since 2016. It shows balance between equity and profit increases, based on share issues and sales respectively.

Both earnings per share represent the profit obtained per basic or diluted share. Their values are observed negative keep decreasing along years. This shows the net losses the company is experiencing and the aggravation of them. However, GomSpace claims that these loses were expected while the company expands.

Finally, the working capital is shown in table G.9 to represent the company liquidity. The 2018 result has decreased compared to 2017 but is still positive. It was negatively affected by trade receivables and contract work, mostly referring to the missed payment of overdue invoices from Sky and Space Global of SEK 33.317M. They were also positively affected by other liabilities, increasing due to the related costs of the rights issue. On the other hand, the Q1 2019 result show a negative value, with a decrease of the capital in about SEK 11M compared to the end of 2018. It was negatively affected by inventories, trade payables and other liabilities. The overcapacity of employees resulted into product manufacturing for stock, increasing the inventories. The costs related to the rights issue from 2018 affected negatively through liabilities. The working capital was beneficed by contract work and trade receivables, based on the received payment from Sky and Space Global of the Critical Design Review of SEK 20.819M.

G.10.2 GomSpace Risks

GomSpace is susceptible to many risks. Its position in the New Space sector makes the company vulnerable to the uncertainties of expansion and growth. Their risks are classified between financial and industry risks.

G.10.2.1 Financial Risks

They are referred to risks involved with capital. Those include credit, interest, foreign currency exchange and liquidity risks. GomSpace is exposed to these risks due to its activities but manages them by following policies approved by the Board of Directors. The company is not involved in speculation of financial risks. The financial risks are presented below [203].

- **Credit risk:** Occur when a counterpart doesn't meet its financial obligations under a contract, leading to a financial loss. GomSpace is exposed to credit risks from its operating (contracts and receivables) and financial (deposits and transactions) activities. The maximum exposure depends on the stipulated amount. From January 1st, 2018, GomSpace implemented IFRS 9 to allow impairment needs assessment of financial assets. They are measured at amortized cost and based on the expected credit loss model. Most of the Group backlog, sales, revenues and trade receivables are generated from few large customers. There is an increased risk that these customers won't meet the financial contracted requirements due to lack of financial resources or other circumstances beyond GomSpace control. Customer credit quality is assessed, and outstanding customer receivables are regularly monitored to ensure financial health. Except from the increased risks of Sky and Space Global, GomSpace evaluation on trade receivables risks is low.
- **Interest risk:** They are present due to GomSpace loans being carried at variable interests. The company states that a change of +/-1% has an effect of SEK 24K in 2019.
- **Foreign currency exchange risk:** GomSpace operates with sales, cost of goods sold and expenses mainly in DKK, USD and EUR. However, they also operate in SEK as they are registered in Stockholm, Sweden. Thus, changes in the foreign exchange rates of DKK, USD and EUR to SEK will have an effect on results and equity. The company has this effect estimated for 2019.
- **Liquidity risk:** It is related to lack of funding and adequate financial liquidity to meet short term financial demands. Due to GomSpace early development stage, the generated cash flow hasn't been sufficient to satisfy the working capital requirements. This situation may prevail, eventually making the company cancel or postpone projects if no external financial sources are obtained. GomSpace manages and monitors funding and liquidity, ensuring availability through cash management and borrowing facilities. The company constantly maintains cash assets or unused credit facilities, ensuring payment capacity and reducing this risk. The payment capacity increased from SEK 102.84M by 2017 to SEK 276.99M by 2018. GomSpace main long-term financing is based on a loan from Vækstfonden under EU's InnovFin SMV Program since 2015. Its fair value, equal to its carrying amount, is level 2 in the fair value hierarchy. However, payment obligations should be settled through cash inflows from operating activities and through proceeds from capital injections.

G.10.2.2 Industry Risks

GomSpace manages risks that may or may not be related to the company, but would affect its business, financial position and future results. The most tangible risks are below [203].

- **New and emerging market:** The market could stagnate or cease to exist. Moreover, the company could see the sector develop in a way they cannot adapt. Competition from other sectors may take over, being better prepared or having greater financial conditions. GomSpace could compete on other terms like price. Then, the challenge will be to secure orders and profitability based on technology development and loyal customers. The increase in modularization and production automation is believed to support growth in the Nanosat industry, something GomSpace does. They also mitigate this risk by monitoring and re-evaluating the business with quarterly forecasts and yearly 5-year plans updates.
- **Key personnel:** Skilled personnel is essential for the proper growth and development of GomSpace, eventually reaching future success. If the company is not able to attract, retain or replace skilled personnel, ongoing projects and development plans may be interrupted. That would bring an adverse impact on GomSpace's business, financial position and future profits. Thus, they try to keep GomSpace as an interesting working place by selecting their locations in attractive areas.
- **Risks relating to the products quality:** GomSpace aims to provide quality products. However, the quality standards of the company and the customers may not meet. A wrong or underachieving product development that doesn't meet market standards, may affect negatively GomSpace business, financial position and future profits. GomSpace Quality Assurance department ensures the performance of the products quality control as well as its periodic registration and monitoring. In addition, the Product Innovation Board validates ongoing and future development projects.
- **Market competition:** Only one competing company is publicly traded, while the others provide limited information. Thus, GomSpace market share is unknown, as well as the competitors' positions, finances and technologies. New actors and technologies, superior to GomSpace's, may arise. They could also threat the market from different sectors, like larger satellites, terrestrial or airborne platforms. The market could experience high competition on price and quality, where a failure in correct development may lead to a loss of offers and market share. GomSpace, with its proven sector experience, tries to be close to its customers and aims to offer them a wide product portfolio.
- **Risks relating to customers:** GomSpace has big agreements with a few large customers (Sky and Space Global, AISTECH, A&M), but they only consider specific and isolated orders. There is a big risk of customers not placing orders or not fulfilling their requirements due to lack of financial resources or other circumstances. The company is also endangered with losing payments if they don't manage to meet the milestone requirements. As specified in the *credit risk*, GomSpace mitigates this risk by taking out debtor insurance, evaluating the customer funding situation. In addition, the company seeks to enter into milestone payments with a positive cash flow.
- **Risks related to acquisitions, subsidiaries and associates:** The results of acquisitions, subsidiaries and associates can sometimes differ from the desired business strategy due to risks, becoming unsuccessful. The subsidiaries acquisition for company expansion may have many economic and logistic risks. Even if the process is successful, the integration of the subsidiary or new company may bring more problems than successes, eventually having to close them. Many expenses arise from subsidiaries closing down and its obligations. GomSpace mitigates the impact of these situations by including in their forecasting an exit strategy for closing down a subsidiary.
- **Execution risk:** According to the Danske Bank analysts Stjerngren and Elvind [171], the most tangible risk for GomSpace is the execution risk. The increase in production and industrialization is a risky phase in any company growth profile. However, they concluded that the actions taken in the facilities predict a highly probable successful transition.

- **Launch of the satellites:** The Danske Bank analysts Stjerngren and Elvind [171] also pointed out the satellite launches as a constraint for the company growth. This sector requires a launch cost reduction in order to keep in concordance with the company growth. Nonetheless, their projections don't expect launch capacity constraints to be an issue due to the CubeSat launching sector current development.

Appendix H: Case Study - Spaceflight

This appendix will present the Case Study of Spaceflight. Spaceflight is presented as a multi service company, which develops activities in four main branches, all of them dedicated to the aerospace sector, focused on products related to Earth Observation. These branches are: Spaceflight Services, Spaceflight Systems, Spaceflight Networks and BlackSky Global. This chapter is divided into History and Overview of the company (section H.1), Business Statement and Philosophy (section H.2), Spaceflight Industries Holding (section H.3), Ownership and Employees (section H.4), EO Market Segment and Requirements (section H.5), Production System (section H.6), Operations (section H.7), BlackSky Spectra, Intelligence Platform (section H.8), Partnerships (section H.9) and Financial Status (section H.10).

H.1 History and Company Overview

The history of Spaceflight started in 1999 when Andrews Space & Technology was founded, which provided space services for commercial, civil and military clients, manufacturing spacecraft components, buses and other systems. Later in 2003, the company was awarded by NASA MSFC for the Alternate Access to Space contract, and it was also chosen in 2006 as one of six finalists for NASA's Commercial Orbital Transportation Services (COTS) program [204] [205].

In 2007, Andrews Space & Technology acquired Automated Controlled Environments, an English company dedicated to aerospace services and subsystems to expand into spacecraft subsystems, however it was officially closed on June 2015 [206].

Later in 2010, Spaceflight services was founded by Jason Andrews and Curt Blakes, with the mission to fundamentally improve access to space by making launch more routineer, cost effective, and with standard flight interfaces. To provide these services, Spaceflight offered launch services together with network communication assistance.

In January 2013, US Army Space and Missile Defense Command funded Spaceflight Industries to design and deliver a Kestrel Eye Block 2A Earth imaging spacecraft as part of the Army's Kestrel Eye program [207].

In 2013, BlackSky Global (BSG) was founded to be part of the Spaceflight Industries group with the aim of launching small satellites as secondary payload with a high-resolution imagery. BSG aims to be the premier global intelligence platform delivering periodic, relevant, and actionable imagery information that allows informed decisions [208].

In order to provide this global intelligence, BlackSky planned to launch a 60-satellites constellation. As a starting point in 2013, an investment of $7.5M Series A was closed to fund BlackSky Pathfinder spacecraft satellite that would not be successfully launched until 2016. At the same time, the first launch for customers Planet and NASA was done through the Spaceflight services.

Later in 2014, Spaceflight Industries started to think about offering the services of a communication network of ground stations for the satellites placed in orbit and unveiled Spaceflight Networks ground station service business.

In 2015, BlackSky made public its own satellite constellation design and business plan. Later, the same year, it closed $21M Series B investment to fund additional BlackSky spacecraft. Additionally, from Spaceflight services, a SpaceX Falcon 9 rocket was purchased to dedicate it to rideshare mission.

In 2016, it started with the closure of a contract with European Global Navigation Satellite Systems Agency (GSA) for satellite launch services. After it, round B.1 of investment was closed with $25M this time. The company OpenWhere was acquired to support the BlackSky Global imagery platform. In November 2016, the first picture taken from BlackSky Pathfinder-1 was publicly released, indicating the success of the first steps of its mission [209].

The first idea was to launch two prototypes, BlackSky Pathfinder-1 and Pathfinder-2, but the second one was finally dismissed as it was planned to be launched in a SpaceX Falcon 9 of Spaceflight, but the multiple launch delays due to the explosion SpaceX launcher had during test preparation in September that year [210], scrapped the plan.

In December 2016, Spaceflight Industries announced the availability of BlackSky Global Intelligence platform which is a cloud-based platform to allow organizations to observe, analyse and act according to the global events that occur, however, until August 2017 it did not announce that BlackSky had been awarded a "*two-year $16.4 million cost-plus-prime contract with the Air Force Research Lab to develop and deliver a cloud-based geospatial intelligence broker platform*" [211]. Meanwhile in April 2017, BlackSky Global Intelligence platform changed its name to BlackSky Spectra to better represent the functionalities and opportunities that offers.

After the announcement of the contract with the Air Force to develop the cloud-based geospatial intelligence broker platform, in September 2017 Spaceflight Industries announced that this project was going to be undertaken in collaboration with the National Geospatial-Intelligence Agency (NGA). This partnership with NGA was an opportunity to provide an agile development approach and to transform from series of early capability demonstrations to a set of tools.

Additionally, in September 2017 another partnership with The Space Alliance1 was signed, with the aim of developing the BlackSky Geospatial Platform. The agreement with Spaceflight Industries included:

- A minor investment in Spaceflight Industries that will help to develop the 60- satellites constellation.
- The creation of a Joint Venture between Thales Alenia Space and Spaceflight in the United States to produce small satellites.
- The implementation of a Joint Cooperation between Telespazio and BlackSky Platform to enhance their products through marketing and analysing portfolios on the market.

In parallel, Spaceflight Industries is awarded in October 2017 with a contract for launch and integration services from NASA's Kennedy Space Centre in Florida in a three-year worth $5.48 million. The contract is to provide launch services for up to 24 payloads, CubeSats standards, in 2018 with options for up to 24 more payloads in 2019 and in 2020.

The data of the main milestones of the company is shown in the timeline of Figure H.1. This may help to visualize the important moments for the company.

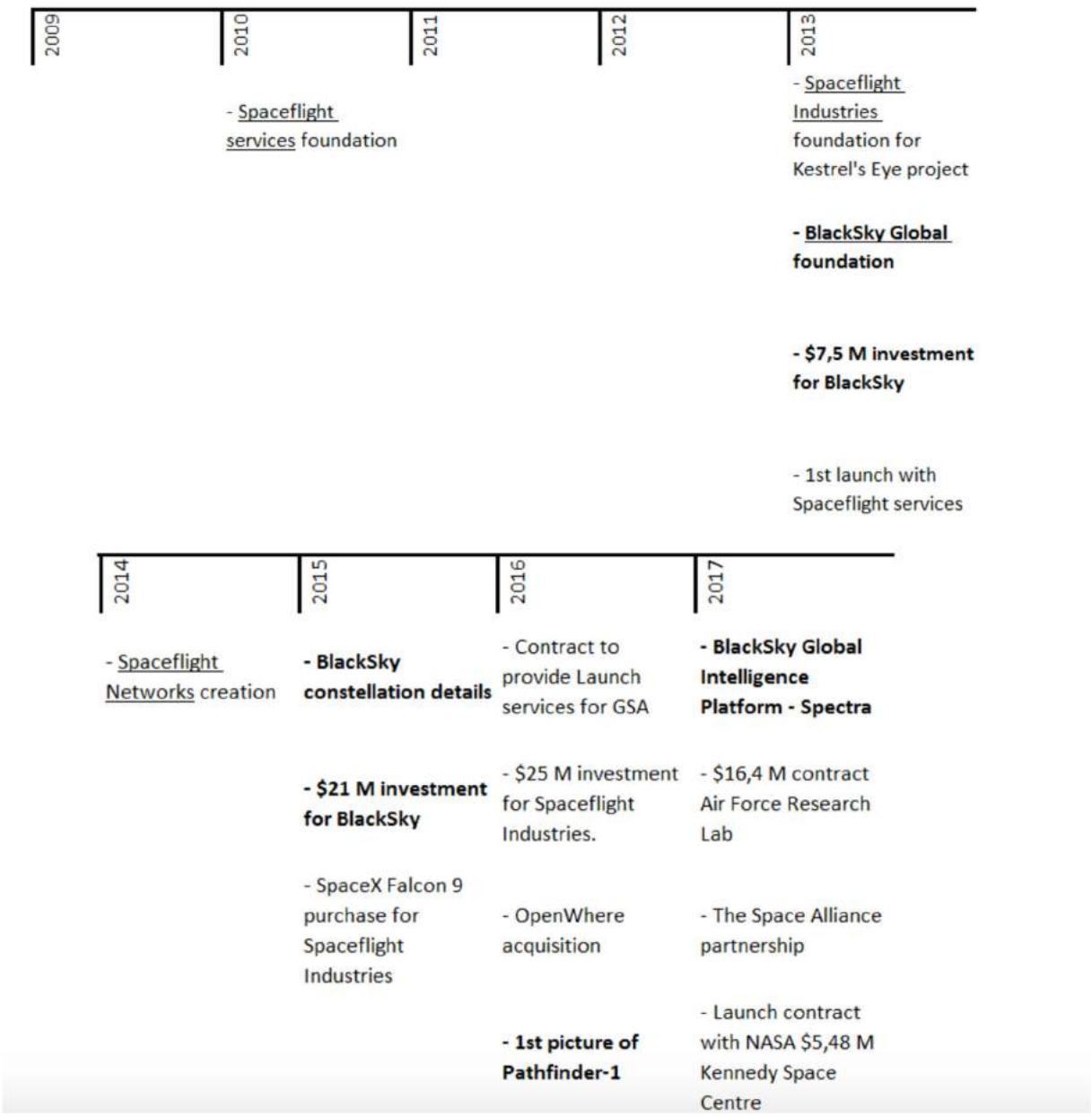

Figure H.1: Timeline with Spaceflight Industries most important milestones.

H.2 Company Business Statement and Philosophy

H.2.1 **Business Statement**

Spaceflight Industries is self-defined in its website as the next-generation space company enabling access to space and redefining global intelligence. Its mission is better detailed such as the approach to "*using up there to make down here better*", which explains that with focusing on making simple the process and reducing costs that once made impossible for some organizations from getting to space and observing our planet. Through the services offered by Spaceflight and BlackSky, the company is allowing affordable access to space.

Some of the slogans that can be found through the website and which define the company's mission and vision are the following [212]:

"We are opening access to space and providing insight about our world."

"We are democratizing space by providing affordable access to space and bringing the unique benefits of real-time insights to more organizations."

"We are using space to solve many of the world's challenges."

H.2.2 **H.2.2 Owner's Equity**

When the idea of BlackSky Global was conceived, the Jason Andrews and the rest of the team working for the US Army Contract Kestrel Eye, realised that there was an increasing demand for more pixels of resolution and also a higher revisit time to provide near-real time information. This revisit time, as it has been explained in previous chapters, meant numerous satellites, but no one has the cash to perform the project. As Jason Andrews explains in the interview with Geospatial Media, BlackSky went to look for investment to develop the constellation, capitalize it and provide the outcomes as a commercial service.

During the first two years, BlackSky raised $28,5 million. Mr. Andrews thinks that the investment community see an opportunity into the global tendency to pass from mapping to activity-based intelligence and he also states that the potential market is of $100 billion.

Spaceflight also counts on the premier venture capital firms as it is an organization backed by these companies, which are [213]:

- Mithril Capital Management.
- RRE Ventures.
- Vulcan Capital.
- Chugach.
- Razor's Edge Ventures.
- In-Q-Tel.

BlackSky plans to pay for its constellation through a combination of investment and income generated from ongoing operations. Jason Andrews, CEO, explained in an article for Spacenews that "our goal in to use venture capital and other capital to build the first 20 revenue-generating satellites. At that point, they should be generating enough revenue to fuel the continued build out of the constellation and the maintenance of the constellation." In the same article in the magazine Spacenews, it is stated that BlackSky has raised $53.5 million through the company Spaceflight Industries.

The management team also works hard to create new contracts and get investments from different companies which end up collaborating with Spaceflight's projects such as Thales Alenia Space, Telespazio, the NGA, the NASA, or the US Government, among others. Also, in the Pitch book [214] website have been found partial information about the funding of Spaceflight Industries.

6 investors appear, which are the companies named above from Venture Capital (VC), and some detailed tables with some unavailable information which are shown below.

Tables H.1 and H.2 show the information about the investments realized to Spaceflight Industries as well as the holding of each of the most important.

Table H.1: *Spaceflight Industries valuation and funding[214].*

Deal Type	Date	Amount	Raised to Date
Later Stage VC (Series A)	31-Dec-2014	$7.5M	$7.5M
Later Stage VC (Series B)	07-Apr-2015	$20.2M	$28.5M
Later Stage VC (Series B)	21-Jun-2016	Unav.	Unav.
Corporate (Series C)	03-Nov-2017	$40.7M	Unav.

Table H.2: *Holding of Spaceflight Industries [214].*

Investor Name	Investor Type	Holding	Board Sert
Telespazio	Corporation	Minority	No
Thales Alenia Space France	Corporation	Minority	No
Mithril Capital Management	Venture Capital	Minority	Yes
Razor's Edge Ventures	Venture Capital	Minority	Yes
RRE Ventures	Venture Capital	Minority	Yes

H.3 Spaceflight Industries Holding

Spaceflight Industries is a holding that includes four separate operating companies. Figure H.2 shows an image of the four companies with the year of foundation and the main activity they perform:

- **Spaceflight Systems**: formerly Andrews Space, founded in 1999 and producer of small high-performance spacecraft and components.
- **Spaceflight Services**: Founded in 2010 to provide launch services to the emerging SmallSat community.
- **Spaceflight Networks**: Created in 2014 to provide communication services to the emerging SmallSat community.
- **BlackSky Global**: Founded in 2013 to unify platform and analytics infrastructure to understand the planet in real time.

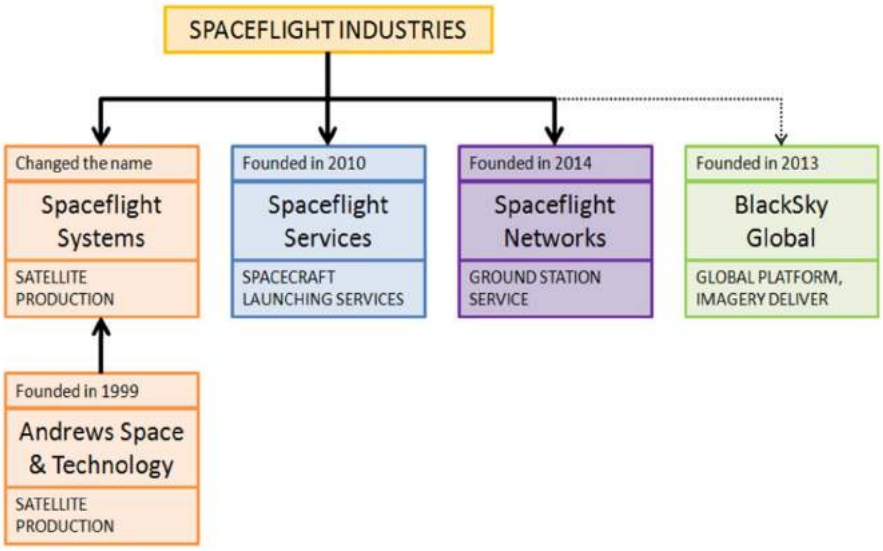

Figure H.2: Parts and functionalities inside Spaceflight Industries.

Although in their conferences, the management team presents Spaceflight Industries as the aggrupation of four parts of the company, the Spaceflight Industries services' website is divided mainly in two parts: Spaceflight and BlackSky. However, the services offered by each part are going to be separated in the following lines and sections:

H.3.1 **Spaceflight Systems**

Spaceflight Systems, Inc. was formerly known as Andrews Space and Technology, founded in 1999 by Jason Andrews. The organization's main activity is the development of satellite components and spacecraft. It offers flight qualified components and subsystems, such as nanosatellite buses, integrated avionics, reaction wheels, control moment gyros, and integrated satellite simulators for small and nanosatellite applications. Apart from that, the company also provides CORTEX avionics, PYXIS star trackers, CubeSat and NanoSat buses, magnetic torque rods, power systems and batteries, solar panels, CubeSat dispensers, spaceflight secondary payload systems, and support services [215].

The CORTEX avionics are, as defined by Spaceflight Industries, a robust, commercial- off-the-shelf (COTS) avionics solution for small satellites and spacecraft, built in slices, where each slice is enclosed in a thin aluminium frame containing the Printed Circuit Assembly (PCA) card and a terminating for external connectors [216].

The PYXIS star tracker is a product designed by Spaceflight, which is a high-performance star tracker for small satellite applications.

H.3.2 **Spaceflight Services**

Spaceflight services objective is to ensure that the customer's mission is on time and budget with end-to-end mission management services offered, as it is stated in the website. In the same site, the company presumes to have launched 112 satellites to date, to have a contract to launch 4,900 kg of mass in satellites, to have served 32 countries and to have 10 different vehicles in network.

With the end-to-end mission management services, Launch & Mission services are detailed below and they include [217]:

1. **Plan:** Contact with Spaceflight in order to define the special characteristics of the spacecraft and the mission itself, to find together the best solution to provide. The company presumes to be able to find the right launch, at the right time, to the right orbit and for the best price.
2. **License:** Spaceflight counts on enough expertise in the field to facilitate the complex licensing requirements for launch.
3. **Integrate:** The spacecraft needs to be integrated to the space vehicle, but Spaceflight offers no problem to do the task. Spaceflight ensures all aspects of satellite integration are considered. Their fixed pricing for launch and integration services include all flight hardware support equipment necessary to successfully integrate, launch and deploy the spacecraft on orbit.
4. **Transport:** The company provides the care needed to carry the spacecraft to the launch site in security conditions.
5. **Launch:** Spaceflight takes care of the last details even in the launch day to ensure that all is in place for the successful deployment.

As Grant Bonin, CTO of Deep Space Industries, states in the Spaceflight Industries website "We need to have a lot of launch vehicle options. The wide range of vehicles Spaceflight provides access to and support is unequalled by anyone else."

The wide range of vehicle that Mr. Bonin refers to are the different models of space vehicles that Spaceflight owns which are a Falcon 9, Minotaur, Soyuz, Polar Satellite Launch Vehicle (PSLV), Antares and Electron, and shown in the next Figure H.3.

Figure H.3: Scheme of the different models of space vehicles that Spaceflight offers to perform launches. [217].

Those vehicles offer different orbit options which are:

- Mid-inclination (MID).
- Sun-Synchronous Orbit (SSO).
- Geostationary Transfer Orbit (GTO).
- Cislunar (CIS)

To complete the launching service offered by Spaceflight and to be coherent with their commercialization of the access to space, in their website the different dates for the launches are offered under the slogan "*Buy a seat, not a rocket".* After it, an interactive tool is put into disposition of the web visitant to find the next scheduled launch that could answer its mission requirements of date, orbit, mass and dimensions of the satellite. A launch schedule is presented with the date, orbit characteristics, satellite size and availability in a way that it is visually easy to see if there is enough space to place the satellite into the launch chosen. All those launches have a link in the end to inquire the place of the flight similar to an airline website to book some tickets. In Figure H.4 it is shown a detail of Spaceflight Industries website.

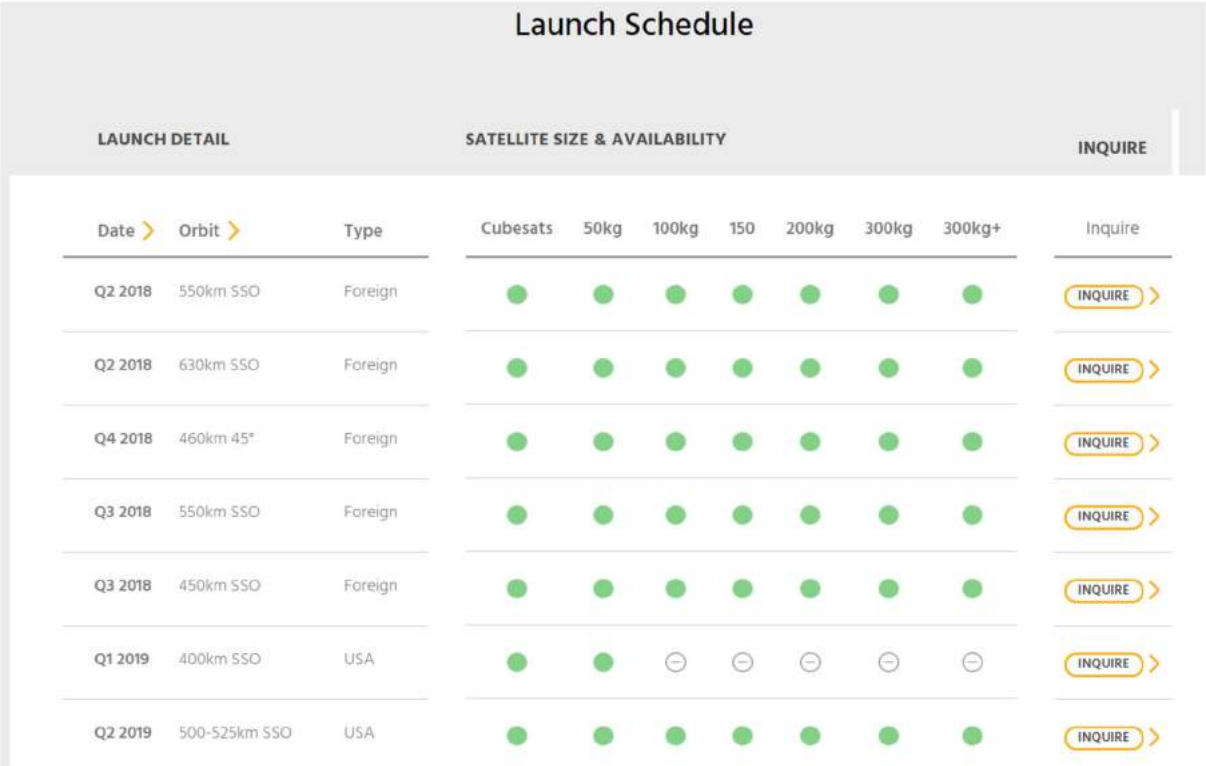

Figure H.4: Detail of the launch application of Spaceflight Industries. Extracted from:[217].

Apart from booking the space of the schedules launches, the website also gives the option to get information from Spaceflight in case a new rocket is needed and also if the orbit needed is not one of the offered by the other destinations scheduled. To end completing the information about the launch service, the complete and updated price list is at the customer's disposition in the same website. Depending on the vehicle selected, the prices can change but they are anyway detailed depending on the satellite mass, the payload type, the dimensions, or if the orbit is Low Earth Orbit or Geostationary Transfer Orbit.

It is also explained the payment method of those services described which is:

- 10% at launch reservation down payment
- 30% at launch minus 24 months.
- 20% at launch minus 19 months.
- 20% at launch minus 13 months.
- 15% at launch minus 7 months.
- 5% at launch.

However, the price paid also includes the procurement of the separation system, the physical integration of the spacecraft to the launch vehicle, management of the launch campaign, International Traffic in Arms Regulation (ITAR) guidance and support for spacecraft registration, Federal Communications Commission (FCC) & National Oceanic and Atmospheric Administration (NOAA) licensing. Figure H.5 shows the pricing of Spaceflight Services depending on the type of payload and type of orbit.

DETAIL	CONTAINERIZED			SATELLITE CLASS							
PAYLOAD TYPE	3U	6U	12U	50kg	100kg	150kg	200kg	300kg	450kg	750kg	1000kg
LENGTH (CM)	34.05	34.05	34.05	80	100	100	100	125	200	300	350
HEIGHT/DIA (CM)	10	10	22.63	40	50	60	80	100	150	200	200
WIDTH (CM)	10	22.63	22.63	40	50	60	80	100			
MASS (KG)	5	10	20	50	100	150	200	300	450	750	1000
PRICE-LEO	$295	$545	$995	$1,750	$3,950	$4,950	$5,950	$7,950	$17,500	$22,000	$28,000
PRICE-GTO	$915	$1,400	$2,750	$4,600	$8,400	$9,800	$11,200	$14,000	CALL	CALL	CALL

Pricing in thousands (USD)

Figure H.5: Table of prices of satellite launches from Spaceflight Industries website [217].

H.3.3 **Spaceflight Networks**

Through the service of Spaceflight Networks, the company plans to provide a full range of communications systems, including satellite radios and a network of global ground stations. These ground stations are placed in the map of the following Figure H.6 where the areas in yellow represent Ultra High Frequency (UHF) sites, and the blue areas are the ones S-band/X-band.

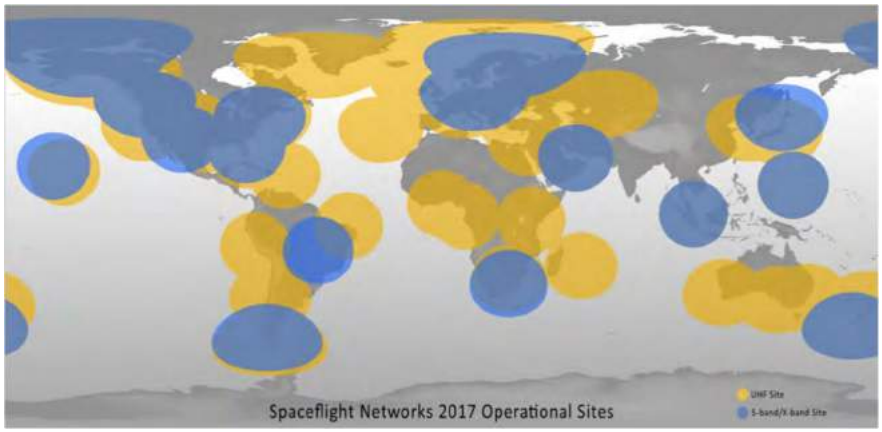

Figure H.6: *Map of Spaceflight Network of ground stations [218].*

Continuing in the same line of the information about the launches, there is the price list established in two different options: Pay per minute or Pay per month.

H.3.4 **BlackSky Global**

BlackSky Global was initially conceived by Andrews when Andrews Space started to work with the US government in the Kestrel Eye project. As Jason Andrews explains in an interview to Geospatial Media, the project of the US Army consisted in putting UAVs in space and a lot of work was done in that direction. After it, they realised that there was a commercial opportunity if a small and economic satellite could provide a high revisit rate that could answer those requirements for the Earth control.

With this information, BlackSky was founded and started to work on the design of the 60-satellite constellation to provide from 40 to 70 revisits per day.

In April 2017, in BlackSky's blog of news, a publication is done "Introducing BlackSky Geospatial solutions", which starts with BlackSky's mission: "BlackSky Geospatial Solutions enables timely and relevant insights by helping our customers accelerate their business" [219].

BlackSky, which is self-defined to be in the pixels business, understands that in the world of big data is important to be conscious about the great opportunities that it provides to gain a deeper understanding about our changing world. With the platform BSG is proposing, the access to data from an ever-growing variety of information sources, sensors, satellites, news feeds, social media and more.

To adequate to these new resources and methods of information many companies would need to migrate, update or enhance their legacy systems and user workflows, but to avoid that challenges, the BlackSky Geospatial Solutions is made to help those organizations, offering expertise in different areas:

- Geospatial Cloud Services.
- Geospatial Software Development, Analytics, and Visualization.
- Machine Learning and Anticipatory Intelligence.
- BlackSky Platform Solutions.
- Geospatial Content, Data Collection, and Integration.

H.4 Ownership and Employees

H.4.1 Leadership

The leadership of Spaceflight Industries is formed by experienced workers in the space sector. The most representative leaders for the creation of the company and the development of its activities are [220]:

- **Jason Andrews (Co-founder, President & CEO - Chief Executive Officer):** started serving at Kistler Aerospace Corporation from 1995 to 1999, holding a range of leadership positions. With a bachelor's degree in aerospace engineering from the University of Washington, in 1999 he co-founded Andrews Space with the mission of being a catalyst in commercialization, exploration and development of space. Later in 2010 Andrews founded Spaceflight Industries to provide cost-effective, widely accessible commercial "rideshare" services, and BlackSky in 2013 to transform how we look at our world, and built world-class teams and operations to support them [221].
- **Curt Blake (President)**: He is president of Spaceflight's launch services group and previously served as senior vice president and general counsel. Curt has led efforts to expand Spaceflight's global network of launch service providers while building relationships with key commercial-, civilian-, and defence-related customers. Mr. Blake oversaw the company's growth from its early commercial rideshare leader on the Antares and Soyuz vehicles to become the industry's rideshare leader and the world's first commercial space line.
- **Dr. Peter Wegner (Chief Technology Officer, CTO):** He was the Director of Advanced Concepts at Utah State University's Space Dynamics Laboratory where he directed investments in new technologies to solve some of the nation's most critical emerging problems. Peter also help positions as the Technical Advisor to Air Force Space Command Directorate of Requirements and a Research Engineer with the Air Force Research Laboratory Space Vehicles Directorate where he developed many key innovations.
- **Brian O'Toole (CTO & Executive Vice-President):** He is responsible for product and technology strategy for BlackSky's global intelligence platform. He joined the company in 2016 when BlackSky acquired OpenWhere, a technology company he founded which delivered on-demand location intelligence solutions to government and commercial customers. Brian brings more than 30 years of executive experience building and growing high performance businesses at start-up. Prior to OpenWhere, he served as chief technology officer at GeoEye, from where he left after a successful $1.3B merger with DigitalGlobe.

H.4.2 **Work Environment**

The company exposes the main key aspects it is focused to offer to its employees. These aspects are [222]:

- **Culture**: Spaceflight is committed to inclusion, collaboration, and having fun while the impossible is made possible. It is offered professional support, a fun work environment, and a hip office overlooking South Lake Union in Seattle or in the heart of aerospace outside of Washington, D.C. in Herndon, Virginia.
- **Professional Growth**: It is a lean and agile team and every employee is expected and empowered to make a significant contribution. Professional development is actively supported, and its growth curve has been exponential.
- **Benefits**: It is offered a competitive salary, a 100% health care coverage for employees, matching 401k, and a slew of other perks. Free snacks and beverages available, “out-of-this-world launch parties” and occasional happy hours.

However, to get the employee’s point of view, a website to evaluate jobs from different companies has been checked with very different results [223].

10 opinions about Spaceflight Industries have been registered from which 6 had negative comments about it, and 3 of them disagreed completely with the way to work of the company. One recurrent comment is the lack of communication between the different departments, with the management team and that many decisions are made without the opinion of the engineering team. Another disadvantage observed is that other support teams such as HR, IT, legal or finance, were understaffed so the services are slow to materialize. The work environment is defined to be frustrating as the technical knowledge of the management teams seems not to be enough, and the lack of organization makes a sensation to have things out of control, including deadlines.

On the other hand, the positive aspects are the great people to work with, which are very good professionals together with the huge exposure to a wealth information in the satellite industry. The team really wants to do things good and the big ideas are stimulating. Another valuated point is that great opportunities can be opened if you prove yourself and they finally trust you. The company offers a work home policy which is well evaluated by the employees that could have experienced it.

H.5 Market Segment

The dimensions of Spaceflight Industries and the holding of the four organizations makes possible for Spaceflight Industries to be able to offer to its customers the integrates value chain for the space sector. From the satellite or equipment development, through Spaceflight Systems, the launching services, with Spaceflight Services, until the mission control, thanks to the Spaceflight Network. With the company BlackSky Global, Spaceflight aims to offer also the final product, the value-added information captured through the satellite of the constellation. However, the analysis of the customer segment doesn’t include Spaceflight Industries customers, as this project is focused on the Earth Observation.

Therefore, the customer segment to be determined is the one BlackSky Global is focused. This organization’s objective is to provide 1-metre-resolution still and video imagery at high revisit rate. In its first steps also, it can be seen that BlackSky Global was almost created to answer a US government project. Considering these characteristics, it can be determined that the EO markets that BlackSky Global is focused on are:

- Defence.
- Maritime surveillance.
- Location Based Service, as this market needs high revisit rate.
- Infrastructure and Engineering, needs the high-resolution data.

H.6 EO Production System

In the interview to Jason Andrews by Geospatial Media, he presented the Spaceflight Industries company's knowledge as capable of building, launching, connecting and operating the satellites that they need to create the constellation. In that sense, all the parts of the companies' group (Spaceflight Systems, Spaceflight Services, Spaceflight Network and Blacksky Global) together perform the complete supply chain to answer the needs related with the aerospace sector, including all the steps of the process. What's more, those companies not only give answer to the project of the BlackSky 60- satellite constellation, but they provide solutions to any customer that could need their experience and services.

This tendency to get knowledge and experience of each of the phases of the aerospace sector can also be observed in the Spaceflight history and also in the strategy acquisitions of determined companies related with the whole process, such as Automated Control Environments, or with its contracts with the US Army.

H.7 Operations

BlackSky Global is planned to deploy a 60-satellite 1m resolution constellation in order to provide the imagery information to be offered through the BlackSky Intelligence Platform. The constellation has been designed to provide a high revisit rate as it has been considered to be the most distinctive advantage from the other imagery providers, about 40 to 70 revisits per day, as Jase Andrews (CEO) estates the interview with Geospatial Media.

This big number of satellites will make possible for BlackSky to provide service to more customers and offer an on-demand service to make possible an instant with analytics solution in less than 90 minutes. In the Figure H.7 there is an image showing the frequency on revisit of each area of the planet with a scale of colours that the complete constellation will provide.

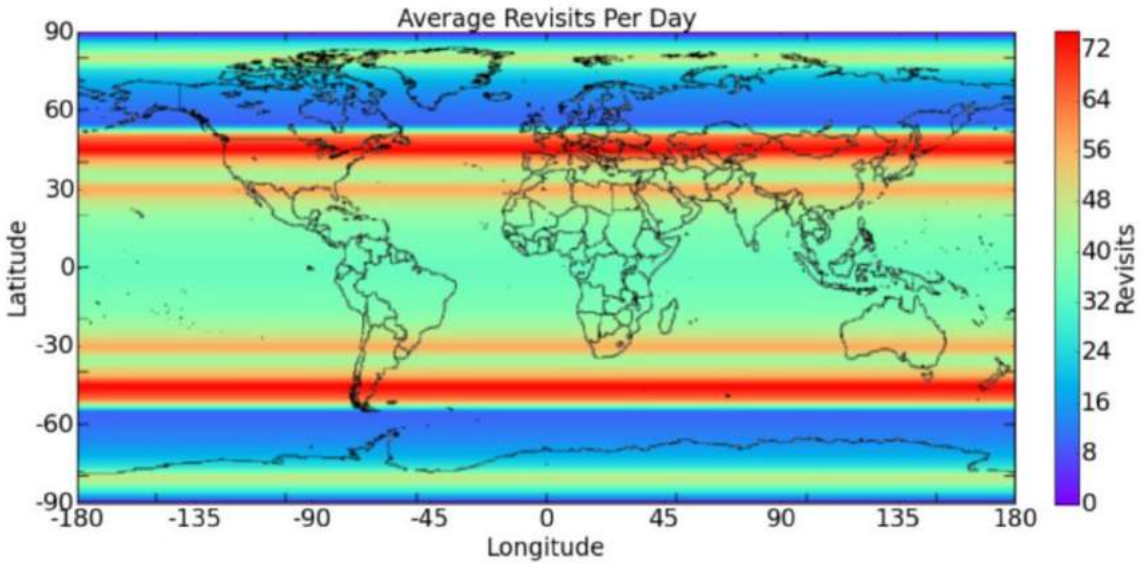

Figure H.7: Revisit rates of the different areas that BlackSky expects to provide with its constellation.

Another characteristic of the constellation is that it is designed for a three-year mission life at the altitude of 450 km. This life length has been chosen to promote the renewal of the technology installed in the satellites [224]. The satellites are designed with an on-board propulsion system that allows them to stay in orbit for the three years of the projected life.

BlackSky's constellation has been designed to operate the satellites at various inclinations with the intention to fly against the rotation of the Earth to get intra-day revisit facilities.

In an interview to Geospatial Media in October 2015, Jason Andrews, CEO, explained the intentions of the company to have 6 satellites deployed in 2016, in LEO between 450 and 550 km altitude, and then another 20 in 2017, 2018 and 2019, having the constellation fully deployed for 2019. However, as time of the launches came, the timing became real and the BlackSky Pathfinder-2 was discarded as a prototype satellite due to the continuous launching delays and the others are still under development. As Scott Herman, vice-president and product development, stated in an article of Spacenews "*We could keep prototyping or get in the game with revenue- generating satellites".*

So, finally in 2015, 6 of the satellites were completely funded and the BlackSky Pathfinder-1 would precede the rest of the constellation as experimental satellites that was finished in 2016. In Figure H.8 it is shown a digital image of the first prototype of the organization.

Figure H.8: Image of Pathfinder-1 of Blacksky.

The objective of the satellite Pathfinder-1 is to validate the imaging System and data processing chain, to achieve high-resolution imagery of 1m GSD. This resolution is considered to be enough to give information about the global economy, to observe cars, trucks, trains, etc. It is the critical one, as a higher resolution would imply bigger and higher-cost satellites while creating some privacy issues. In Table H.3 there are the main technical characteristics listed.

Table H.3: Technical characteristics of Pathfinder-1.

ASPECTS	CHARACTERISTIC
Launch	September 26, 2016 (PSLV)
Lifetime	3 years
Orbit	690 km SSO of SCATSat-1 LTAN=9:20h
Orbit Period	98,4’
Imaging Mode	Stills
Images Per Day	20
Aperture	24 cm
On Board Storage	30 GB
Spectral Bands	RGB 400-510 nm (blue). 510-580 nm (green). 590-750 nm (red).
Resolution	0,9 - 1,1 m
Swath	Image Area 4,4 km x 6,6 km
Mass	48 km

Peter Wegner, CTO of Blacksky, states in an interview with Spacenews, that the company will start to receive its first revenues from some agreements already done through the imagery received from the first six satellites and Pathfinder-1.

Additionally, Mr. Wegner is asked by Spacenews, about the difference between BlackSky and other companies which have similar business models, such as Planet Labs and Skybox, to which he replied explaining that their objective is moving up in the value chain and also, the possibility to allow the customer to tap the satellites directly and let them choose the pictures it takes. In the same line, Jason Andrews, in the interview with Geospatial Media states that companies like Planet Labs, Airbus or DigitalGlobe can be understood as potential clients instead of competitors.

H.8 BlackSky Spectra, Intelligence Platform

One of the main objectives of BSG is to Transform how we look at the planet as it is repeated many times in its website. The main application of the work performed by BlackSky, which is the part of Spaceflight Industries directly related with the Earth Observation, the topic of this work, is to help users to make accurate decisions based on the current and most real-time events that occur in our planet.

With the aim of introducing a “game changing” platform, BlackSky Spectra is the premier global intelligence platform delivering timely, relevant, and actionable information so that the customer can make swift and informed decisions. It integrates a diverse set of sensors and data unparalleled in the industry to provide an “unprecedented view of the world”. Satellite imagery is combined with social media, news and other data feeds to create timely and relevant insights. In the website, the process proposed is to [225]:

- **Observe:** Discover, purchase and download the imagery from BlackSky’s sources, including 10 high resolution spacecrafts. It is also possible to task satellites to take current images or to monitor areas of interest. The method used is like adding items to the shopping cart.
- **Analyse:** With machine learning, predictive algorithms, and natural language processing, BlackSky delivers critical geospatial insights about an area of interest. Data is synthesized from a wide array of sources including social media, news outlets, radio communications and even earthquake sensors.
- **Act:** The platform alerts of critical events empowering the customer to take immediate action on business operations, humanitarian efforts, illegal activities, or natural disasters, providing a holistic view of the situation.

BlackSky Spectra gives an on-demand service access to customers to imagery from different sources such as from France’s Airbus Defence and Space, South Korea’s SI Imaging Services, China’s Twenty First Century Aerospace Technology Co. and UrtheCast of Canada.

This imagery platform was presented on BlackSky’s website on April 2017, explaining all details of its performance. The imagery service is presented as the source of many different types of data including visual imagery, synthetic aperture radar (SAR), hyperspectral images, radio frequency detections, video and more.

In Figure H.9 it can be seen the different products that the on-demand imagery service, Spectra, can offer, providing at the same time a visible image, SAR and IR, mixing lots sources from different satellites as are Airbus Pleiades, Airbus TerraSAR-X, and USGS Landsat.

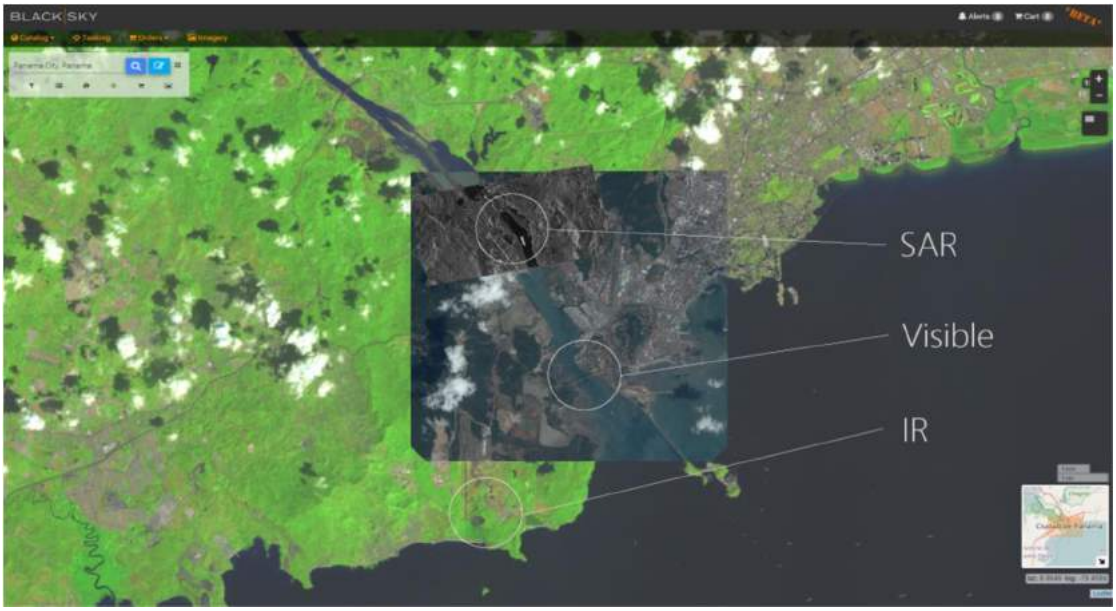

Figure H.9: Example of the type of imagery available in the Spectra platform.

In the presentation post of Spectra, some main characteristics are exposed to differentiate it from the other similar imagery platforms. Those characteristics are:

- Its broad expansion. It allows access to imagery from their global sensor network which includes many satellite-based sources, meaning about 12 high- resolution spacecrafts and over 25 million images. Some of the sources of the images are from Airbus Pléiades, SPOT6/7, KazEOSat-1, TerraSAR-X, 21AT's TripleSat, UrtheCast's Deimos-2, SIIS's KOMPSAT.
- The possibility to point and shoot. The application has the functionality to allow the directly task in the virtual constellation from BlackSky Spectra, if the image need is not available in the catalogue. It is as easy as point the area on a map and introducing the frequency of the pictures taken.
- Its possibility to go back in time. Spectra can search by location, resolution, date of the picture, or specific vendor. Also, using the source of archive images it provides a baseline view of a specific location and is powerful for monitoring change over time.

Additionally, Spectra shows the density over any area for any sensor worldwide. It gives to users the information about how often an area is imaged.

H.9 Partnerships

Within this section, the most relevant partner relationships that Spaceflight Industries currently has established will be presented, as well as the purposes which these partnerships aim to fulfil:

- **Mitsui & Co. Ltd and Yamasa:** Spaceflight Industries reached an agreement with this Japanese company, by the end of 2018 with the purpose of selling its satellite rideshare subsidiary, Spaceflight Inc. to this company. [226] The deal would see Spaceflight continue to operate as an independent business based in the U.S and headquartered in Seattle, with the same mission of providing rideshare launch services for small satellite payloads. [227]
- **NGA:** In September 2017, both companies announced the achievement of a partnership agreement in order to develop and deliver a cloud-based geospatial intelligence broker platform for the U.S Air Force Research Lab. Under this contract, BlackSky will design and develop a GEOINT Broker Development Platform for evaluation by analysts, including those within the NGA. This program continued BlackSky's support of the Predictive GEOINT Prototype (PGP). [228]
- **NASA:** In 2017, both entities signed an agreement of collaboration regarding the launch of U-class payloads. The multi-year contract, which was signed, covered launch services in 2018 for a maximum of 24 payloads, with options to provide launch services for up to 24 additional payloads in 2019 and 2020. The U-Class payloads flown by NADA, often created by universities and non-profit organizations, played a foundational role in the agency's technology developed, and included investigations in planetary exploration, Earth observation, and fundamental Earth and space science. [229]
- **Thales:** In February 2019, Thales partnered with Spaceflight Industries in order to disrupt the smallsat industry, by producing cost-effective satellites at a new state-of-the-art smallsat production facility. The both created the LeoStella, a smallsat design and manufacturing company. The first satellite produced by LeoStella will be an Earth-Observation satellite for the BlackSky's constellation. [230]
- **Telespazio:** In September 2017, Spaceflight Industries and Telespazio signed a partnership agreement for the realization of the BlackSky constellation, for Earth Observation. This agreement included the following elements: [231]
    - A minority investment of Telespazio in Spaceflight Industries to enhance the production of BlakSky's small satellites.
    - The creation of an industrial Joint Venture in the U.S between Thales Alenia Space and Spaceflight Industries, specialized in the production of small satellites.
    - The implementation of a Joint Cooperation and Marketing Agreement enhancing both parties product and analytics portfolios on the market.

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