UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH

Escola Superior d'Enginyeries Industrial, Aeroespacial i Audiovisual de Terrassa

Study of the Business Model of three Earth Observation (EO) companies already present in the Very Low Earth Orbit market (VLEO)

Report

Master's degree Thesis in Aerospace Engineering
Master Universitari en Enginyeria Aeronàutica (MUEA)

Juan Felipe Gutiérrez Baena

Director: Silvia Rodriguez Donaire

Departament d'Organització d'Empreses

June 8, 2020

(This page was intentionally left in blank.)

Disclaimer

This document reflects only the authors' view and the European Commission is not responsible for any use that may be made of the information it contains. This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 737183.

UNIVERSITAT POLITÈCNICA DE CATALUNYA - BARCELONATECH

Abstract

Escola Superior d'Enginyeries Industrial, Aeroespacial i Audiovisual de Terrassa
Departament d'Organització d'Empreses

Master of Science

Study of the Business Model of three Earth Observation (EO) companies already present in the Very Low Earth Orbit market (VLEO)

by Juan Felipe Gutiérrez Baena

The emergence of a new private spaceflight industry has taken the Earth Observation (EO) sector by surprise. NewSpace companies are challenging the traditional satellite sector by addressing their services to mass market requirements of high-quality and low-cost EO. As part of the DISCOVERER project, this study aims to determine the Key Success Factors to consider by a new EO company at Low Earth Orbit (LEO). Hence, three businesses fitting the description were analyzed with the Case Study Methodology to establish their Business Model Canvas (BMC), associated Patterns, and Key Success Factors. The investigation consolidated the newly proposed Democratizing Business Model Pattern and added new characteristics. Successful EO NewSpace firms are getting divided between integrated operators, integrated manufacturers, and end-user specialists. A new EO company should consider the Democratizing Pattern success factors and the Vertically Integrated Strategies (VIS), depending on its disruptive idea and resource capabilities. Further research is needed to identify new factors, strengthen the validity of the Pattern, and VIS tendencies.

Key Words

Earth Observation; NewSpace; Business Model Canvas; Patterns; Space Democratization; Spire Global; GomSpace; Aistech Space

Estudi del Model de Negoci de tres empreses dedicades a l'Observació Terrestre ja presents al Mercat de *Very Low Earth Orbit*

El sorgiment d'una nova indústria espacial privada ha pres per sorpresa al sector de l'Observació Terrestre (EO). Les empreses de NewSpace estan desafiant al sector dels satèl · lits tradicionals dirigint els seus serveis als requisits del mercat massiu de l'Observació Terrestre d'alta qualitat i baix cost. Sent part del projecte DISCOVERER, aquest estudi té per objecte determinar els factors d'èxit clau que ha de tenir en compte una nova empresa d'Observació Terrestre en LEO. Per consegüent, es van analitzar tres empreses ajustades a aquesta descripció amb la metodologia de l'Estudi de Casos per a establir el seu BMC, els Patrons associats i els factors clau del seu èxit. La recerca va consolidar el recentment proposat Patró de Model de Negoci per a la Democratització de mercats i li va afegir noves característiques. Les empreses exitoses d'EO NewSpace s'estan dividint entre operadors integrats, fabricadors integrats i especialistes en usuaris finals. Una nova empresa d'EO ha de tenir en compte els factors d'èxit del Patró Democratitzador i les Estratègies Integrades Verticalment (VIS), depenent de la seva idea disruptiva i els seus recursos. És necessari continuar investigant per a identificar altres factors i enfortir la validesa del Patró Democratitzador i de les tendències en VIS.

Estudio del Modelo de Negocio de tres empresas dedicadas a la Observación Terrestre ya presentes en el Mercado de *Very Low Earth Orbit*

El surgimiento de una nueva industria espacial privada ha tomado por sorpresa al sector de la Observación Terrestre (EO). Las empresas de NewSpace están desafiando al sector de los satélites tradicionales dirigiendo sus servicios a los requisitos del mercado masivo de la Observación Terrestre de alta calidad y bajo costo. Siendo parte del proyecto DISCOVERER, este estudio tiene por objeto determinar los factores de éxito clave que debe tener en cuenta una nueva empresa de Observación Terrestre en LEO. Por consiguiente, se analizaron tres empresas ajustadas a esta descripción con la metodología del Estudio de Casos para establecer su BMC, los Patrones asociados y los factores clave de su éxito. La investigación consolidó el recién propuesto Patrón de Modelo de Negocio para la Democratización de mercados y le añadió nuevas características. Las empresas exitosas de EO NewSpace se están dividiendo entre operadores integrados, fabricantes integrados y especialistas en usuarios finales. Una nueva empresa de EO debe tener en cuenta los factores de éxito del Patrón Democratizador y las Estrategias Integradas Verticalmente (VIS), dependiendo de su idea disruptiva y sus recursos. Es necesario seguir investigando para identificar otros factores y fortalecer la validez del Patrón Democratizador y de las tendencias en VIS.

Acknowledgments

I would like to thank my supervisor, Silvia Rodríguez Donaire, for her guidance throughout the process. Her support helped me to get motivated during this long project. I would like to acknowledge all members of the DISCOVERER project for allowing me to contribute with my work.

My biggest thanks go to my family for all their support. To my amazing wife, Małgorzata, for always telling me not to give up, for understanding my struggles and guiding me, and for easing everything so I could finish my studies. To my daughter Mia for unconditionally putting a smile on my face every day. To my parents, sister, and family-in-law for understanding how important this was for me, providing everything I could possibly need, and more.

Honor Declaration of Authorship

I declare that,

- the work in this Master Thesis is completely my own work,
- no part of this Master Thesis is taken from other people's work without giving them credit,
- all references have been clearly cited,

I understand that an infringement of this declaration leaves me subject to the foreseen disciplinary actions by *The Universitat Politècnica de Catalunya - BarcelonaTECH.*

Title of the Thesis: Study of the Business Model of three Earth Observation (EO) companies already present in the Very Low Earth Orbit market (VLEO)

Juan Felipe Gutiérrez Baena	....	June 8, 2020
Student Name	Signature	Date

Contents

List of Figures

List of Tables

Acronyms

A&M Aerial & Maritime Ltd. 50, 51, 53, 59, 82, 84, 87, 90, 92, 99, 100, 112, 119–121

ADCS Attitude Determination and Control System. 38, 40, 65–69, 72–77, 79

ADS-B Automatic Dependent Surveillance-Broadcast. 14, 16, 22, 23, 29, 30, 36, 38–41, 43, 46, 49–51, 53, 59, 61, 67, 68, 74–79, 82–84, 91–93, 95, 97–100, 112, 121, 125

AI Artificial Intelligence. 29, 41, 52, 82, 117, 124

AIS Automatic Identification System. 14, 16, 22, 26, 28, 29, 38–42, 44, 45, 51, 59, 61, 68, 79, 82–84, 91, 92, 98–100, 112, 121, 125

AIT Assembly, Integration, and Testing. 30, 31, 33, 93, 99

API Application Programming Interface. 41, 43, 44, 71, 106, 107, 118, 122, 124, 127, 128

BMC Business Model Canvas. 1, 2, 105, 106, 108–112, 114–116, 127

BMSS Business, Marketing, Sales, and Support. 26, 28

CAAS Civil Aviation Authority of Singapore. 51, 84

CAVIS Cloud, Aerosol, Vapor, Ice, and Snow. 15

CCD Charge-Coupled Device. 15, 16

CCS Command and Control Subsystem. 26, 28

CEO Chief Executive Officer. 21, 25–27, 47, 49, 55–57

CFO Chief Financial Officer. 55, 56

CINAE Centro Gallego de Innovación Aeroespacial. 92, 101, 112

CMOS Complementary Metal-Oxide Semiconductor. 37, 75

CNES Centre National d'Études Spatiales. 75, 76

COTS Consumer-Off-The-Shelf. 37, 49, 60, 62, 71, 76, 79, 80, 107, 109, 110, 113, 115, 117–120, 124

CSP CubeSat Space Protocol. 61, 64, 65, 71, 74, 76, 98

CTO Chief Technology Officer. 21, 26, 56, 57

ECSS European Cooperation for Space Standardization. 71, 76

EO Earth Observation. 1–7, 9–12, 14–17, 22, 28, 35, 38, 57, 58, 60–62, 67, 74, 75, 80–82, 84, 91, 95, 96, 106, 107, 109, 115, 118, 125, 127–129

EPS Electrical Power Subsystem. 62, 68, 75, 76, 79

ESA European Space Agency. 9, 24, 44, 50–52, 69, 71, 73, 75–81, 83, 91, 101, 118–120

FPGA Field-Programmable Gate Array. 61, 65, 77

GEO Geostationary Earth Orbit. 7, 8, 11

GIS Geographic Information Systems. 44

GNSS Global Navigation Satellite System. 24, 29, 36, 38, 42, 43, 76

GNSS-R Global Navigation Satellite System Reflectometry. 30, 36, 38, 42

GNSS-RO Global Navigation Satellite System Radio Occultation. 14, 16, 24, 26, 28, 30, 38, 39, 42, 44

GPS Global Positioning System. 38, 39, 66, 68, 76, 80, 81

GPS-RO Global Positioning System Radio Occultation. 14, 16, 22, 24, 38, 39

HEO High Earth Orbit. 7

I2C Inter-Integrated Circuit. 37, 66, 69, 71, 75

ICAO International Civil Aviation Organization. 23, 30, 43, 93

ICD Interface Control Document. 71

IOD In-Orbit Demonstration. 35, 38, 49–53, 65, 67, 68, 71, 73–76, 79–83, 85, 92, 93, 98–100, 109, 115, 119, 127, 128

IoT Internet of Things. 49, 59, 68, 96, 99, 115

IR Infrared. 5, 6, 14, 16, 22, 37, 38, 60

ISL Inter-Satellite Link. 51, 60, 61, 63, 65, 73, 79, 82

ISS International Space Station. 22, 34, 35, 45, 75, 76

LEO Low Earth Orbit. 1, 2, 4, 5, 7, 8, 11, 14, 34, 35, 38, 42, 43, 48, 63, 64, 71, 74, 76, 103, 127

LEOP Launch and Early Orbit Phase. 70, 72, 80

M-ARGO Miniaturized Asteroid Remote Geophysical Observer. 52, 67, 82, 83

M2M Machine-to-Machine. 96, 98, 99

MBA Master of Business Administration. 26, 55, 56, 94

MCOP Mega-Constellations Operations Platform. 51, 69, 70, 73, 83, 120, 124

MEMS Micro-Electro-Mechanical Systems. 66

MEO Medium Earth Orbit. 7

MoU Memorandum of Understanding. 23, 51, 52, 84, 92, 100

MS Multi-Spectral. 5, 15, 16, 121

MST Multi-Spectral Telescope. 96, 99, 112

NIR Near Infrared. 15, 16

NOAA National Oceanic and Atmospheric Administration. 22–24, 30, 46

NPI Non-Polar Inclined. 14

OBC On-Board Computer. 61, 64, 65, 67, 68, 71, 74, 76, 79, 82, 97

PPE Property, Plant, and Equipment. 86

RF Radio Frequency. 26, 28, 33, 59, 61, 64, 76, 109, 110, 124, 125

RGB Red, Green, and Blue. 15, 16

SDK Software Development Kit. 65, 66

SDR Software Defined Radio. 49, 50, 59, 61, 63–65, 73–77, 79

SSO Sun-Synchronous Orbit. 8, 14, 35, 79, 99

SWIR Short-wave infrared. 15

TEC Total Electron Content. 29, 38, 42

TTC Telemetry, Tracking, and Command. 98

UAV Unmanned Aerial Vehicles. 5, 6

UHF Ultra High Frequency. 32, 34, 35, 63, 64, 67, 68, 73–76, 79, 97

VHF Very High Frequency. 37, 39, 51, 59, 63, 64, 73, 84

VIS Vertically Integrated Strategies. 33, 70, 117, 123–129

VLEO Very Low Earth Orbit. 1, 2, 4, 5, 8–10, 80, 81, 100, 127

Nomenclature

D Aperture diameter [m].. 9

P Power density [W/m^2].. 9

λ Wavelength [m].. 9

h Satellite altitude [m].. 9

r Ground resolution [m].. 9

1 | Introduction

This first introductory chapter will cover the Aim of the Project, the Scope, the Requirements, and the Justification regarding the Earth Observation (EO) sector. The last section will mainly focus on the methods used with satellites at Low Earth Orbit (LEO) or Very Low Earth Orbit (VLEO).

1.1 Aim of the Project

The project aims to study three companies operating in the Earth Observation sector at Very Low Earth Orbit and Low Earth Orbit using the Business Model Canvas (BMC). Then, their Key Success Factors will be identified.

1.2 Scope

An introduction and a general review on EO will start this report in the State of the Art. Then, the study of the three companies established in the EO business contains the sections below, when possible.

- The History and Overview of the company.
- The Business Statement and Philosophy.
- The Ownership and Employees.
- The EO Market Segment and Requirements.
- The On-line Platform.
- The Production System.
- The Operations.
- The Payloads in the satellites and their Applications.
- The most important Partnerships.
- Financial Status and Risks.

Once each firm has been studied, an assessment of their Case Studies will include the aspects below.

- Analysis of each company, creating its BMC and identifying its Business Model Pattern.
- Identification of each firm Key Success Factor.
- Comparison of companies and selection of the most promising.

Ultimately, the general project issues listed below are acknowledged.

- Environmental impact study.
- Limitations and possible future trends.
- Conclusions.

1.3 Requirements

This project will fulfill the requirements shown below.

- The studied companies should have their focus on Earth Observation, and their operations should include Nanosatellites in LEO or VLEO.
- The methodology to analyze the firms must be the Business Model Canvas.
- The companies must be already operating at least one satellite.

1.4 Justification

The new emergence of the private spaceflight industry, also known as NewSpace, is taking the sector by surprise. Even though a clear definition of the NewSpace does not exist in consensus, Hay et al. from The Tauri Group stated that "*NewSpace includes companies that are likely to be flatter, flexible organizations that are consumer-focused, innovative, willing to take risks, and focused on new technology solutions*" [119, p. 6]. The same paper designates traditional space saying that "*Traditional space companies are more likely to be highly structured and focused on established lines of business, often with the government. They are also more likely to be established in sectors with high-value offerings, low sales volume, and low growth*" [119, p. 6].

The traditional EO space companies have dominated the sector using traditional business models and having governments as anchor customers. NewSpace companies untie from the anchor costumers and address their services to mass market requirements for high-quality, low-cost EO. This innovative trend to commercialize space is growing at speed to have about 10,000 new companies in the next ten years. The EO NewSpace companies find their compelling arguments in the differences and challenges they represent for the traditional EO satellite sector [152].

- While traditional EO companies need governments as anchor costumers to mitigate financial risks, NewSpace companies count with private capital and the promise of EO products and services sales to mass markets.

- As customers value both spatial and temporal resolution, NewSpace companies cannot accomplish due to their assets. While the latter can provide weekly revisits, the former proposes under-hourly satellite passes. Thanks to cost/satellite betting, better on-orbit availability and in on-demand imaging are possible.

- NewSpace companies challenge traditional EO data costs with announcements of up to $1\,\$/km^2$ for new imaging, while current pricing for traditional satellites stands at about $10\,\$/km^2$ for 1 m resolution and $50\,\$/km^2$ for under 0.5 m.

- Instead of raw images, or with only basic post-processing, from traditional EO firms, NewSpace companies plan on an end-to-end product approach. They provide analytics solutions using their big data to end-user applications.

- NewSpace EO businesses are basing their operations in constellations of smaller satellite platforms such as CubeSats or Microsatellites. These satellites have on-orbit lifetimes from six months to up to five years. The platform decision depends on the planned resolution, which increases with the payload aperture size and leads to larger satellite sizes. These satellite constellations present cost-effective advantages against the several hundred million dollars a traditional EO satellite could cost.

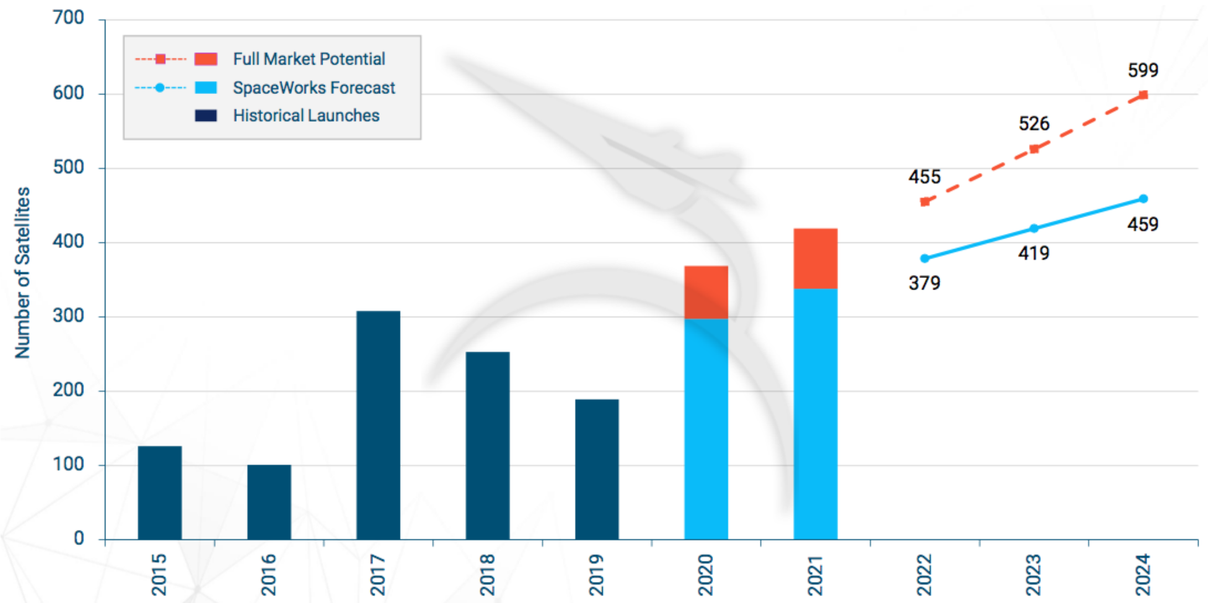


Figure 1.1: 2020 Nano/Microsatellite Launch History and Market Forecast. *Image credit: Williams and DelPozzo [226].*

SpaceWorks has released several market forecasts for Nano and Microsatellites. Their primary focus is on the satellites from 1 kg to 50 kg, the range where most of the satellite activity occurs.

The 2020 SpaceWorks analysis indicates that over 300 of these satellites where launched in 2017, surpassing the previous year prediction with a yearly increase of 205%. The launches decreased gradually until 2019, but they still double the value from 2016. In consequence, SpaceWorks updated its 2020 and 5-year forecast projections, expecting similar values than 2017 and between 1.800 and 2.400 Nano/Microsats launches in the next five years. This increase results from more Small satellite launch opportunities, more mature sector operators, and a more robust financial capital influx for the companies. Figure 1.1 is a graphic representation of this launch forecast and historical records until 2019. The 2020 SpaceWorks estimations predict 298 new Nano/Microsatellites launches, rebounding the industry from a down year in 2019 [226].

Even though Nano and Microsatellite missions have their focus on EO, some have other sectors of interest. The historical data from 2009 to 2013 showed that EO and Remote Sensing applications in Small satellites only constituted 12%, while technology purposes dominated with 55%. The forecast from 2014 to 2016 showed that the EO sector would increase up to the point of dominance, with 52% [14]. This prediction was confirmed when the historical data from 2015 to 2019 showed that the EO sector made up 51% of the Small satellites launched. Figure 1.2 shows it together with the prediction from 2020 to 2024. The latter shows that even though the EO sector will still dominate the Small satellite launches, a reduction to 45% will happen. Another important conclusion from these predictions is the increase of the communication applications

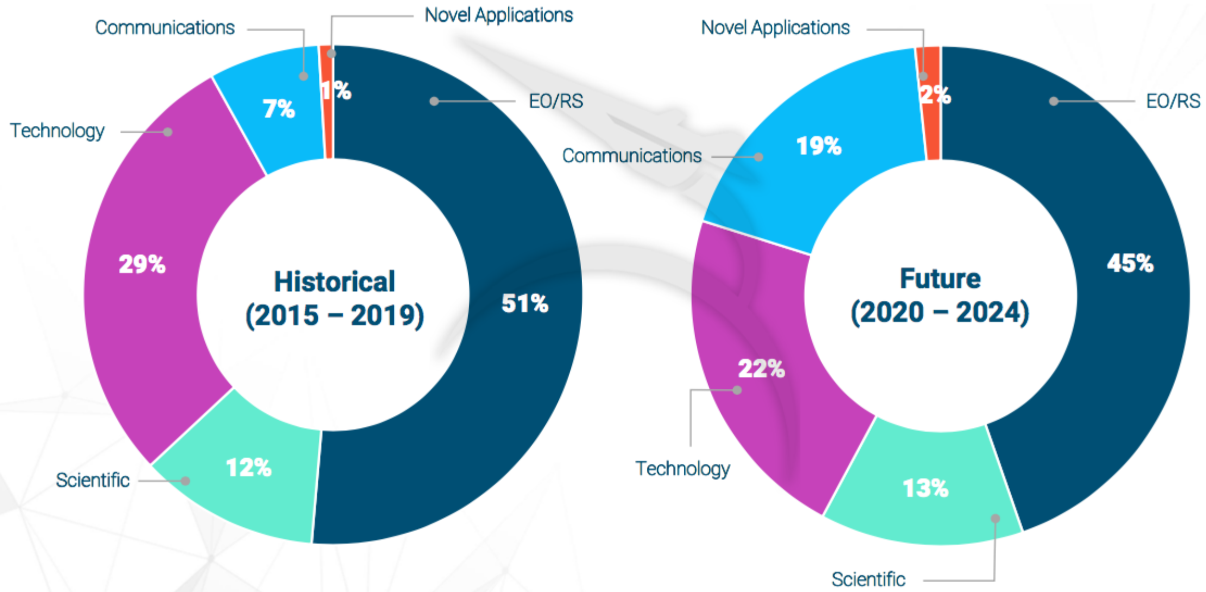


Figure 1.2: Nano/Microsatellite Trends by Application (1 kg to 50 kg). *Image credit: Williams and DelPozzo [226].*

of Small satellites to 19% in the next five years. However, the communications sector raised questions about its future market role when, after a massive surge in 2018, it nearly dissipated in 2019 [226].

Regarding the growth of the space EO market, and the commercialization of space, exploration of the companies taking part in it must be performed. Identifying the Key Success Factors of these businesses with operative satellites at LEO and VLEO is of great interest. They should provide the reasons why these firms are considered promising or stand out from the rest.

2 | State of the Art

This chapter will introduce some definitions regarding EO, the different methodologies to achieve it, its potential, and finally, a review on space EO with a focus on VLEO.

2.1 Earth Observation

According to the over 100 governments partnership Group on Earth Observations, Earth Observation is the gathering of data and information about the Earth's physical, biological, and chemical systems, whether atmospheric, oceanic, or terrestrial. Space-based, ground-based, remotely, and in situ sensed data help perform the assessment and monitoring of natural and human-made environments [118]. Thus, companies can perform EO in multiple ways. Even though this project analyzes the businesses that operate satellites at LEO or VLEO, a quick review on potential competitor's methods for remote EO is provided.

2.1.1 Unmanned Aerial Vehicles in EO

The usage of Unmanned Aerial Vehicles (UAV) is one of the most popular methods for remote EO. They provide operational versatility and flexibility in terms of platform, location, cost, time, and repeatability. When an operation presents a high human risk, a UAV is preferred than a crewed aircraft to safeguard lives. They can fly slow and at low altitudes while still acquiring high temporal and spatial resolution data, which is an advantage against satellite systems [207]. Additionally, UAV remote sensing is known for its relatively low cost and very high spatial resolution. However, instability can blur images, and geographic distortion or errors may occur when data is processed into field images [24].

A UAV bases its versatility on the extensive range of options the platform can adopt, the numerous onboard sensors available, and their interchangeability. Some examples are the visible-spectrum, thermal and Infrared (IR) cameras, light detection and ranging devices, Multi-Spectral (MS) and hyperspectral Sensors, atmospheric, or magnetic sensors [159, 207].

2.1.2 Manned Air Vehicles in EO

Crewed Air Vehicles or Manned Aircrafts observation is the most traditional EO method. The differential characteristic of it is the presence of humans inside the sensing platform. The most significant advantages compared to UAVs are the higher image resolution and the long periods in the air, which result in quicker coverage of larger areas of a landmass. Some missions demand crewed aircraft by regulations [32, 19]. When compared to satellites, these vehicles have higher temporal frequency and resolution due to the proximity to the studied terrain, providing better identification and mapping of tiny objects. Thus, this method is more appropriate for medium-size terrains with complex topography and small objects of interest, where 3D interpretations are helpful [146]. A crewed aircraft can be versatile as they have relative flexible availability, high spatial resolution, and interchangeability of sensors. However, this method comes at a high cost and weather dependence [24].

Some examples of Manned Air Vehicles adapted for remote sensing tasks are in the military sector, modifying commercial general aviation aircraft to perform these tasks. Dassault Aviation has configured the Falcon 2000 as the Maritime Multirole Aircrafts, being able to perform maritime reconnaissance, surveillance, piracy control, drug interdiction, or medical evacuation [156]. Embraer has adapted its EMB-145 to host Airborne Early Warning and Control, and Maritime Patrol systems [220]. Finally, the BAe146-301 research jet from BAE Systems serves as a non-military example. Operated by the Facility for Airborne Atmospheric Measurements, it can mount sensors such as trace gas and ozone analyzers, radars, video cameras, nephelometers, Infrared (IR) spectrometer, or multi-function instruments. This plane helps to study the atmospheric boundary layer, the land and sea surface properties, and the troposphere [42].

2.1.3 Satellites in EO

As satellite EO is the main topic of this project, further sections will show it in-depth (i.e., section 2.3 LEO and VLEO orbits in EO), leaving this section only to compare this method to others. Satellite EO provides clear, reliable, and stable images covering extensive areas. Besides, some providers may offer the imagery free of charge, with historical data and high storage capacity being available. Unlike UAV and crewed aircraft methods, once a satellite is orbiting, there is no need to plan an EO mission for every time imagery is required.

The principal drawback of this EO method is the high cost required to develop, maintain, and exploit it. They increase exponentially with the imagery spatial resolution. As a satellite orbit has a fixed schedule, it cannot provide the desired image at a particular daytime. Clouds could also cover the ground features at the satellite passing instant. Furthermore, significant sets of images may need evaluation and sorting to obtain proper results. Finally, communications between ground stations and satellites sometimes underperform, needing them to be visible to each other. Therefore, data could get lost or not collected at a critical time [24].

2.2 The market opportunities for EO

Earth Observation can be very useful in many fields, and companies should take profit from this situation. According to the Probst et al. [164] Case Study, the Anderson et al. [14] report, and the Group on Earth Observations working topics [118], the main EO application areas are listed below.

- **Environment and Climate Change:** EO could sense data of the atmosphere, oceans, and land around significant geographical areas. By linking this data to other monitoring systems, it is possible to monitor desertification phenomena, identify gaps in biological and taxonomic information, track non-endemic invasion of species, or assess the global biodiversity trends. It would aim biodiversity and ecosystem sustainability, including water resources management.
- **Disaster Resilience and Humanitarian Aid:** Forecasting and preparation for natural

disasters mitigate their risk. EO acquired data aids these actions, improves the first responders' coordination, and increases the support for decision-making during epidemics, earthquakes, fires, floods, or volcanoes eruption. The information helps to monitor the long-term recovery and relief efforts after a disaster, refugee movements, and infrastructure development in conflict areas.

- **Energy and Natural Resources Management:** Remote sensing can improve the selection of new energy or natural resources production sites, and can monitor the already-known sources. More sustainable exploitation of resources like oil, gas, or carbon is possible. The data could facilitate substantial increases in renewable energy production.
- **Food Security and Sustainable Agriculture:** In order to support precision farming and water management of cropland, EO can monitor crop health, soil moisture, surface temperature, photosynthetic activity, pest infestations, and irrigation levels. Sustainable agriculture and correct food identification, quality, and safety, lead to food security, and could end hunger.
- **Public Health Surveillance:** The involvement of EO regarding public health could include air quality, water carrying disease alerts, or health facilities access assessing. The data could bring better public awareness and supporting policies at all levels, reducing the number of fatalities and illnesses.
- **Urban Development, Infrastructure, and Transportation Management:** High-resolution maps can provide better urban and regional planning, assuring balanced and sustainable development. Monitoring and management of infrastructures and transportation can minimize environmental impacts, and increase overall safety, efficiency, and competitiveness while reducing costs and moving towards a low-carbon footprint. Maritime transportation could be the most improved sector thanks to ship or container activity monitoring.
- **Blue economy[1]:** To increase marine knowledge, EO can help develop a sustainable marine economy in maritime and coastal tourism.
- **Security and Defence:** Capturing most investments, Security and Defense applications are the most developed and widespread. Very high-resolution satellite data will continue to support border control and military on-the-field operations. However, other markets are experiencing the highest amount of growth.
- **Insurance Modeling:** EO can support risk exposure modeling, monitor and asses hazard and damage, increasing efficiency and profitability.

2.3 LEO and VLEO orbits in EO

Satellites performing remote sensing usually orbit in Low Earth Orbit, from 200 km to 2,000 km, or Geostationary Earth Orbit (GEO), at 35,786 km. SInvestigations to place EO

[1]The Blue Economy is the sustainable use of ocean resources for economic growth, improved livelihoods, and jobs while preserving the health of the ocean ecosystem [227].

satellites in Medium Earth Orbit (MEO) and High Earth Orbit (HEO) include the National Oceanographic and Atmospheric Administration satellite systems [30], the interferometric Synthetic Aperture Radar systems [25], or highly elliptical orbits for continuous polar regions imaging [209].

The LEO orbits provide high spatial and low temporal resolutions, while the GEO orbits are characteristic for low spatial and high temporal resolutions. GEO satellites achieve high temporal resolutions because they orbit at the Earth's rotational speed and can remain over an exact location, while LEO satellites have to orbit at higher velocities [30]. However, NewSpace companies are approaching the temporal resolution issue with larger constellations of smaller satellites at LEO orbits.

In a Very Low Earth Orbit, the satellite average altitude remains below 450 km [216]. Even though it constitutes a subset of LEO, the capital difference between higher LEO and VLEO orbits is the significant role of the atmosphere, that cannot be neglected below 500 km

2.3.1 VLEO challenges

The atmosphere and the lower distance to the ground present some challenges for satellites at VLEO [216]. They are listed below.

- The denser atmosphere generates aerodynamic forces on the satellite. The drag makes the spacecraft reduce its velocity, making it lose altitude and change its orbit. Thus, the satellites incorporate low drag configurations and propulsion systems to counterbalance the resistance and increase their lifetime. Low drag configurations may limit the satellite attitude change, but aerodynamic forces could control the satellite attitude and orbit. Pieces of evidence are the usage of aerodynamic forces to maintain a decaying satellite in a Sun-Synchronous Orbit (SSO) [217], or the drag modulation to control an atmospheric re-entry interface through the decay rate [215].
- The atmosphere at VLEO is principally composed of Atomic Oxygen, the most abundant element from 180 km to 650 km. When the Sun's ultraviolet radiation strikes the residual diatomic oxygen, it photodissociates into atomic oxygen. Their recombination with atoms of oxygen or nitrogen occurs at lower rates because the density of the atmosphere at this altitude is too low. The atomic oxygen is highly reactive and can deteriorate optical and thermal coatings. Mechanical properties and mechanisms can also be affected if their lubrication gets attacked. Companies use materials with high density and graphite in order to reduce this effect [16].
- The satellite communications window to downlink the collected data to a ground station gets reduced as the altitude decreases. The passage time gets reduced due to an orbital velocity increase and an elevation angle constraint. If a VLEO satellite needs a downloading data rate of a higher-orbit satellite, innovative solutions should emerge. The two dominant trends are the usage of higher bandwidth communications, and the data transmission to communication satellite relays at GEO. The latter allows extending the communication time and window.

2.3.2 VLEO benefits

The multiple benefits of VLEO have motivated NewSpace companies to exploit it. They are attractive enough to justify selecting these orbits, and investigation to overcome their challenges. Virgili Llop et al. [216] and Gonzalez et al. [117] summarized some advantages of EO at VLEO.

- It **increases the Resolution of Optical Payloads**. The Rayleigh criterion states that the diffraction of light entering an optical system limits its maximum resolution. The essential metric to determine an EO satellite mission is the ground resolution on objects, summarized in equation 2.1, where r is the ground resolution, h is the satellite altitude, λ is the wavelength (for the visible spectrum $\lambda = 550\,\text{nm} = 5.5 \cdot 10^{-7}\text{m}$) and D is the aperture diameter.

$$r = 1.22 \frac{\lambda h}{D} \tag{2.1}$$

  There are three solutions to increase the ground resolution (r); to improve the quality of the optics, to enlarge the aperture diameter (D), or to reduce the satellite operational altitude (h). The first one is expensive and has the theoretical constrain of the diffraction limit. The second one needs larger satellites, which implies launching and development expenses. Finally, reducing the altitude increases the ground resolution proportionally.

- The **Radiometric Performance increases** thanks to the closer distance from the satellite to the imaging target. Radiometry is the technique used to measure electromagnetic radiation. The power density of a signal is proportional to the inverse square distance from its source, as shown in equation 2.2, where P is the power density of the signal, and h is again the altitude of the satellite.

$$P \propto \frac{1}{h^2} \tag{2.2}$$

  A reduction of the satellite altitude (h) improves the signal-to-noise ratio in optical and radar payloads. It also reduces the satellite power consumption in favor of other transmission subsystems. The lower altitude allows obtaining the same results with less sensitive instruments than in traditional orbit missions, therefore reducing the costs.

- The **Available Launcher Payload Mass increases** compared to higher orbits. As the orbit altitude increases, the mass a launcher can bring to it decreases exponentially. Thus, the cost of a VLEO mission drops significantly compared to higher-orbit missions, using smaller launchers to deliver similar payloads. Therefore, a launcher could put entire satellite constellations in orbit at once.

- Satellites **do not require Disposal Maneuvers** in order to de-orbit. The European Space Agency (ESA) recommends that every satellite inactive for over 25 years should re-enter the Earth's atmosphere if it orbits below 2,000 km. Hence, most spacecraft need de-orbit devices such as propulsion or drag sail systems. These systems are unnecessary at VLEO as the drag becomes an asset to aid re-entry. Moreover, as these satellites have reduced lifetimes, the re-entry occurs before the 25-years limit.

- The **Geospatial Position Accuracy increase** due to a shorter spacecraft-to-target distance. The angle, position, and attitude uncertainties propagate less, reducing the geolocation error of the imagery and data collected. So, cheaper attitude determination systems can deliver similar performance results at VLEO than high-orbit satellite systems.
- The **Effective Surveillance Footprint Size increases** thanks to the target's shorter distance. The lower a satellite flies, the larger the number of satellites that will comply with a minimum resolution requirement. It also improves the revisit factor.
- It provides a **low risk of Collision with Space Debris**. The higher atmosphere density at this altitude makes the satellites decay at higher rates. Thus, the orbit clears itself faster than at higher orbits, where the probability of collision is high. VLEO is an alternative to higher orbits, which continue to get more crowded and polluted. Space debris is considered a significant threat to high-orbit space missions.
- A **Disruptive Propellant System** could run using the atmosphere particles found at these altitudes. The mass of a satellite will get reduced if there is no need to launch it with maneuvering propellant onboard. Hence, satellites could be lighter, smaller, could include more instruments or larger apertures at no weight or size cost.
- The **Radiation Levels are lower** than at higher orbits thanks to the inner Van Allen belt and the Earth's Magnetic Field, which protects satellites from the radiation of solar particles. Furthermore, the lower orbit decreases the threat of solar activity effects, like solar flares or coronal mass ejection. The Van Allen belts and the cosmic rays will mainly affect satellites at VLEO. The cosmic rays are high-energetic particles that originate outside the Solar System and can cause intense ionization when passing through matter.

2.4 Satellites on Earth Observation

According to the Union of Concerned Scientists, from the 2,666 operational satellites in April 2020, 884 had EO as their purpose. It represents a growth of 15% compared to April 2019, and of 29% compared to April 2018. The share EO satellites have overall orbiting spacecrafts has been similar the last three years at 35% in 2018, 37% in 2019, and 33% in 2020 [210]. There are many types of satellites available for EO missions and are classified by mass in Large/Medium satellites (over 500 kg) and Small satellites or Smallsats (under 500 kg). Similarly, experts categorize Smallsats into Minisatellites (101 kg to 500 kg), Microsatellites (11 kg to 100 kg), Nanosatellites (10 kg to 1 kg), and smaller categories with no interest for this study.

2.4.1 Large and Medium Satellites

These are considered the most traditional spacecraft. Medium satellites have a mass from 501 kg to 1,000 kg, while Large ones have masses over 1,001 kg. Traditional satellites differentiate not only from Smallsats in their mass but also in their building process. Tens of thousands of people get involved in the process, forming part of big, structured, and formal organizations. Small satellites get developed by small and interactive teams of dozens of members, working from concept to launch and operation. Only the wealthiest countries can afford Large satellites, involving the cooperation of a few major companies and government laboratories. Smallsats development resembles that of personal computers at their origin [44].

Remote sensing Large satellites provide higher resolution and accuracy than Smallsats. High stability is their key feature, but it implies increases in platform cost, size, and systems sophistication. Even if organizations use Smallsats and Large satellites for imagery, they fulfill different needs. However, Large and Medium satellites could become a threat to Smallsats if they increase their revisit rates. This scenario is not likely to happen in the next 10 to 15 years. GEO orbits cannot offer low-latency, and even if these satellites improve, they would not have the benefits of LEO orbits [140]. In April 2020, there were 242 active EO Large satellites, representing 27.38% of the total EO platforms [210]. Table 2.1 summarizes the fundamental characteristics of some Large and Medium satellite constellations, among others. Then, Table 2.2 shows those constellation satellites in detail.

2.4.2 Minisatellites

With a mass from 101 kg to 500 kg the Minisatellites had great importance during the first Smallsats phase between 1995 and 2000. Together with the Microsats, they represented about 65% of the Smallsats, specially impulsed by the commercial communication service firm Globalstar. After this era, its growth decelerated, as companies focused mostly on individual satellites for remote sensing or scientific missions. By 2014, the Globalstar (72), the Russian government Gonets (25), and the Russian military Kosmos (30) communication constellations comprised most of the Minisats, which was around 250 at the time [222].

The number of operative EO Minisats in April 2020 was 91, representing 10.29% of the total EO satellites. Most of them have a military or government use, but some have commercial purposes. Constellation examples of the latter are the DMC 3 from the UK-based Surrey Satellite Technology, the RapidEyes produced by the German RapidEye AG, or the Skysats by the US-based Planet Labs [210]. Table 2.1 summarizes the central characteristics of some interesting Minisats, among others. Tables 2.2 and 2.3 show their satellites in depth.

2.4.3 Microsatellites

Since 1995, Microsatellites have had a similar tendency than Minisats. With masses from 11 kg to 100 kg, their pioneer satellites were for the Orbcomm communications constellation. The second Smallsat phase saw Microsats dominate in research, development, scientific, and communication fields. However, they are experiencing a slowdown since 2010, when more standardized Nano and Picosatellites, like the CubeSat, emerged. By 2014, the US-based Orbcomm launched 40 of them, added to an estimated 300 total orbiting Microsats [222].

There was 105 operative EO Microsats in April 2020, representing 11.88% of the total EO satellites. Most of them have a military or government usage, but some are commercial. Some examples of the latter are the Jilin 1 constellation from the Chinese Chang Guang Satellite Technology, the Finish ICEYE-X1 from ICEYE, the US-based BlackSky Pathfinder 1, and the ÑuSat constellation from the Argentinian Satellogic [210]. Table 2.1 shows the principal features of some interesting Microsats constellations, while Tables 2.2 and 2.3 present their satellites.

2.4.4 Nanosatellites

With masses from 1 kg to 10 kg, the Nanosatellites have the principal role in the third Smallsat phase that started in 2013. The rise of NewSpace has strong relations with the growth of these satellites. The US-based company Planet Labs has been a significant contributor in the Nanosats development, deploying 93 new commercial remote sensing 3U CubeSats in 2014. It is precisely the CubeSat standard that revolutionized the Nanosatellites [222].

Figure 2.1 displays the Nanosatellite numbers, with 687 operational Nanosats on April 19, 2020. On the same date, Kulu [139] reported 1,317 launched Nanosats in history. A few days before, in April 2020, 359 Nanosats were listed as performing EO missions, representing 40.61% of the total EO satellites [210].

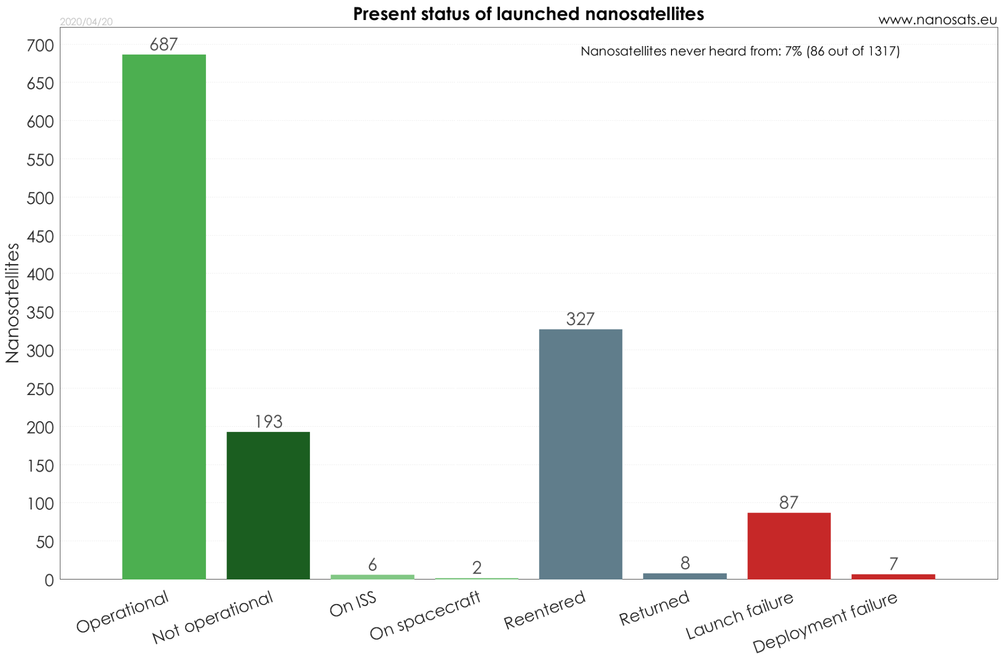


Figure 2.1: Current status of launched Nanosatellites (April, 2020). *Image Credit: Kulu [139].*

CubeSats

The general requirements of the CubeSat Design Specifications define this type of Nanosatellite. The standardization began in 1999 when two university professors were trying to provide affordable access to space for the scientific university community. It brought reductions of technical developments and scientific investigations costs. CubeSats popularity has spread among Government agencies and companies as they facilitate access to space and encourage researchers to investigate these small units.

Standard cube units of 10 cm sides and masses from 1 kg to 1.33 kg form a CubeSat. The combination of the units builds the standard architectures, where a digit followed by a U represents the number of cubic units (e.g., 1U, 2U, 3U, or 6U). The standardized shape reduces business costs associated with transport and space deployment and allows mass-production, using off-the-shelf components. Reduced development time in CubeSats has allowed the increase of multiple launches [26].

There are other standard structures like the CubeSats that have smaller dimensions. They are the PocketQubes, with 5 cm cube units, the TubeSats, with 0.75 kg tube units, or the SunCubes, with 3 cm cube units. Depending on their mission configuration, sometimes they do not reach the 1kg mass mark to classify as Nanosats.

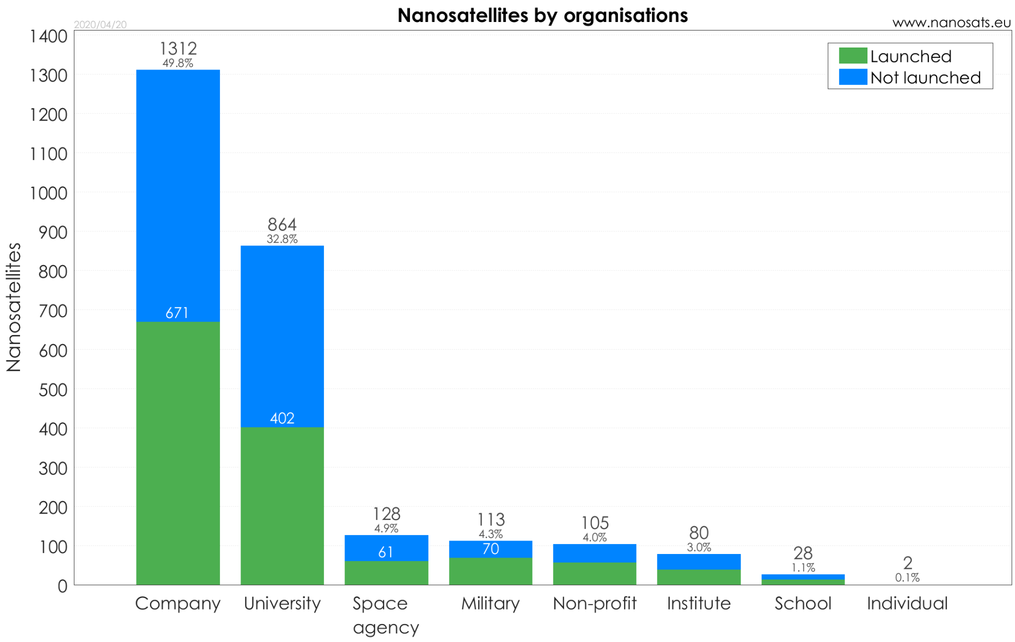


Figure 2.2: Nanosatellites share by organization type (April, 2020). *Image Credit: Kulu [139].*

As Kulu [139] states, from those 1,317 Nanosats launched, 1,210 are CubeSats. Figure 2.2 shows how commercial organizations have the biggest share of Nanosats, followed by universities. Together they corner the 82.6% of these satellites, dominated by CubeSats. Examples of them are the Cicero 6Us from US-based GeoOptics, the Lemur 3Us from US-based Spire Global, and the extensive Dove 3Us by US-based Planet Labs [210]. Table 2.1 summarizes the key characteristics of various interesting Nanosat constellations, while Table 2.3 presents their satellites in depth.

Table 2.1: List of commercial EO Constellations [147, 210, 35, 134, 228, 139, 40, 170].

Name	Company	Country	Satellites	Type	Orbit	Objective
Maxar	Maxar Technologies	US	WorldView, GeoEye, Radarsat (5/6)	Large	LEO, SSO	To provide freshly-updated high-resolution imagery library thanks to accurate, agile, and great capacity satellites that collect optical, IR, and radar imaging.
Spot	Spot Image	France	Spot 6/7 (2/2)	Med	LEO, SSO	Provide continuous sustainable wide-swath high-resolution observation services.
SuperView	Beijing Space View Technology	China	SuperView-1 (4/16)	Med	LEO, SSO	First Chinese commercial very high-resolution EO company providing mapping, land use, urban planning, agricultural, oil and gas exploration, maritime, security, defense, and intelligence.
DMC-3	Surrey Satellite Technology	UK	SSTL-S1 (4/4)	Mini	LEO, SSO	Optical imaging purposed constellation with daily revisits intended for change detection, disaster monitoring, mapping terrain, strip imaging, and wide areas mosaic imaging.
RapidEye	RapidEye AG (Planel Labs)	Germany	RapidEye (5/5)	Mini	LEO, SSO	To provide EO products and services for agricultural insurance, large producers, international institutions, and cartography.
Jilin-1	Chang Guang Satellite Technology	China	Jilin-1 (15/60)	Mini, Micro	LEO, SSO	China's remote sensing constellation for commercial use provides optical imaging, help with harvest assessment, geological disaster prevention, and resource surveys.
Zhuhai-1	Zhuhai Orbital Aerospace	China	OVS, OHS (13/34)	Micro	LEO, SSO, NPI	Survey natural resources, cities, crops, forests, and other environmental features using video, hyper-spectral, radar, IR, and high-resolution imagery satellites.
Aleph-1	Satellogic SA	Arg.	Ñusat (7/98)	Micro	LEO, SSO	Collect Earth's real-time multi-band, optical, hyper-spectral, and video imagery for commercial markets with 1 m ground resolution.
CICERO	GeoOptics Inc	US	Cicero (7/24)	Nano (6U)	LEO, SSO	A LEO 6U CubeSats constellation that performs high-accuracy GNSS-RO for global weather pattern and surface remote sensing.
Lemur-2	Spire Global Inc	US	Lemur-2 (88/150) 115 launched	Nano (3U)	LEO, SSO, NPI	Meteorology data for commercial customers through GPS-RO (Stratos), and worldwide ships and aircraft tracking through AIS (Sense) and ADS-B (AirSafe).
Flock & SkySat	Planet Labs Inc	US	Dove (231/430), SkySat (15/27)	Nano (3U), Mini	LEO, SSO, NPI	Constellation for optical EO with high ground resolution, coverage, and cadence, daily capturing the whole Earth.

Table 2.2: List of commercial EO satellites [147, 40, 210, 35, 134, 228].

Name	Constel.	Mass	Orbit	Launcher (Date)	Contractor	Instrumentation/Payload
Worldview 1/3 (3)	Maxar	2,500 kg, two 2,800 kg	496 km, 770 km, 617 km	Delta 2 (1 9/18/07, 2 10/8/09), Atlas 5 (3 8/13/14)	Ball Aerospace	Panchromatic (all; resolution 0.5 m, 0.46 m, and 0.31 m), 8 MS (2, 3; res. 1.85 m and 1.24 m), 4 SWIR (3; res. 0.31 m) and CAVIS (3; res. 30 m) sensors.
Radarsat-2	Maxar	2,200 kg	798 km	Soyuz (12/14/07)	MacDonald, Thales Alenia	C-Band Synthetic Aperture Radar with 1 to 100 m panchromatic resolution and <15 m Nadir accuracy.
GeoEye-1	Maxar	1,955 kg	681 km	Delta 2 (9/6/08)	General Dynamics	Panchromatic and 4 MS sensor with 0.41 m and 1.65 m ground resolution.
Spot 6/7 (2)	Spot	720 kg	697 km, 650 km	PSLV (6 9/9/12, 7 6/30/14)	Airbus D&S	Panchromatic and 4 MS sensor with ground resolution of 1.5 m and 6 m.
SuperView-1 (4)	SuperView	560 kg	530 km	CZ-2D (1-2 12/28/16, 3-4 1/8/18)	China Aerospace ST	PMS-3 Panchromatic (res. 0.5 m) and 4 MS CCD camera with Visible/NIR radiometer (res. 2 m).
SSTL-S1 (4)	DMC-3	447 kg	650 km	PSLV (1-3 7/10/15, 4 9/16/2018)	Surrey Satellite Tech	Panchromatic (res. 1 m) and 4 MS imager (res. 4 m).
RapidEye (5)	RapidEye	150 kg	630 km	PSLV (8/29/08)	Surrey Satellite Tech	CCD 5 MS push broom Earth imager capturing RGB, Red Edge and NIR (Nadir res. 6.5 m).
Jilin-1 Shipin (8)	Jilin-1	95 kg, 165 kg, 208 kg	650 km, 535 km	CZ-2D (1-2 10/7/15), Kuaizhou-1 (3 1/9/17), CZ-6 (4-6 11/21/17), CZ-11 (7-8 1/18/18)	Chang Guang STL	High-definition Gaze mode video imager (1-2, with 4K HD color video, res. 1.13 m; 3, res. 0.92 m; 4-8, dual with Push Broom, shimmer, inertial space imaging, res. 1 m).
Jilin-1 Gaofen (3)	Jilin-1	95 kg, 42 kg	545 km, 565 km	Kuaizhou-1 (2A 11/13/19, 2B 12/7/19), CZ-11 (3 6/5/19)	Chang Guang STL	Push Broom pancromatic color (2A-2B, res. 0.75 m; 3, res. 1.06 m) and MS (2A-2B, res. 3 m; 3, res. 4.24 m) imager with image swath (2A-2B at 40 km; 3 at 17 km).
Jilin-1 Guanpu (2)	Jilin-1	95 kg	530 km	CZ-11 (1/21/19)	Chang Guang STL	Push Broom, hyper-spectral imager with 26 spectral bands, 5 m resolution and 150 km swath width.
Jilin-1 Guangxe-A	Jilin-1	400 kg	650 km	CZ-2D (10/7/15)	Chang Guang STL	High-definition, Push Broom, Stereo imagers for pancromatic (res. 0.72 m) and MS (res. 2.88 m).
Jilin-1 Kuanfu	Jilin-1	95 kg	485 km	CZ-2D (1/15/15)	Chang Guang STL	High-definition, Push Broom, pancromatic (0.75 m) and MS (3 m) imager with 136 km swath width.

Table 2.3: List of commercial EO satellites 2 [170, 139, 210, 35, 134, 228].

Name	Constel.	Mass	Orbit	Launcher (Date)	Contractor	Instrumentation/Payload
OVS (5)	Zhuhai-1	55 kg, 90 kg	540 km, 500 km	CZ-4B (1A-1B 6/15/17), CZ-11 (2-2A 4/26/18, 3A 9/19/19)	Zhuhai Orbital Aerospace	High-definition, Push Broom video system (1A-1B, res. 1.98 m; 2-3A, res. 0.9 m) capturing 20 frames per second (2-3A, 120 s sequences and 2,500 km length images).
OHS (8)	Zhuhai-1	55 kg, 90 kg	500 km	CZ-11 (2A-2D 4/26/18, 3A-3D 9/19/19)	Zhuhai Orbital Aerospace	Hyper-spectral, Push Broom imager with 10 m ground resolution, 150 km swath width, and 2,500 km length images.
Ñusat (7)	Aleph-1	35 kg, 45 kg	500 km	CZ-4B (1-2 5/29/16, 3 6/15/17), CZ-2D (4-5 2/2/18, 7-8 1/15/20)	Satellogic SA	Panchromatic, MS, hyper-spectral, and thermal IR imaging payload with 1 m, 1 m, 30 m and 90 m ground resolution. 4K HD video in all bands.
Cicero (7)	CICERO	10 kg	500 km	Soyuz 2.1a (1-3 7/14/17), PSLV (6 6/23/17, 7 1/12/18, 8 11/29/18), Electron (10 11/11/18)	Tyvak Nanosats Systems	Cion Global Navigation Satellite System Radio Occultation (GNSS-RO) payload for remote sensing of Earth's weather, climate, environment, and surface.
Lemur-2 1-77 (54)	Lemur-2	4.6 kg	400 km to 640 km	Various; 11 Launches from 9/28/2015 to 02/01/2018	Spire Global Inc	Stratos GPS-RO / GNSS-RO and Sense Automatic Identification System (AIS) payloads.
Lemur-2 78-115 (34)	Lemur-2	4.6 kg	485 km to 580 km	Various; 7 Launches from 5/21/2018 to 12/11/2019	Spire Global Inc	Stratos GPS-RO / GNSS-RO, Sense AIS, and AirSafe Automatic Dependent Surveillance-Broadcast (ADS-B) payloads.
Dove (231)	Flock	4.7 kg	470 km to 620 km	Various; 14 Launches from 4/19/2013 to 11/27/2019	Planet Labs Inc	Combination of telescope and CCD camera that capture RGB and NIR imagery. Three types; PS0/PS1 are a 2-element optical system with 11MP CCD camera, PS2 is 5-element with 29MP.
SkySat (15)	SkySat	110 kg	500 km	Various; 6 Launches from 11/21/2013 to 12/3/2018	Space Systems / Loral	Panchromatic, MS RGB, and NIR image sensors with ground resolution of 1 m.

3 | Case Study Methodology

The methodology used for the research of the selected companies is known as the Case Study Methodology. This method is a form of research, such as surveys, experiments, histories, and archival records. As Yin [230] states, when the research question is *how* or *why*, the researcher should select the Case Study Methodology as he has no control over behavioral events, and the focus of the study is a contemporary phenomenon. Yin defines a Case Study as "*an empirical inquiry that investigates a contemporary phenomenon in depth and within its real-world context, especially when the boundaries between phenomenon and context are not clearly evident*" [230, p. 18]. Thus, the cases of the willing-to-be-studied companies fit the method perfectly because there is a will to understand each case as it might bring essential conclusions.

On the other hand, as phenomenon and context are not always distinguishable, there is a need to define a Case Study research method. Yin says that "*a Case Study inquiry copes with the technically distinctive situation ... of more variables of interest than data points, and as one result relies on multiple sources of evidence, with data needing to converge in a triangular fashion, and as another result benefits from the prior development of theoretical propositions to guide data collection and data analysis*" [230, p. 18].

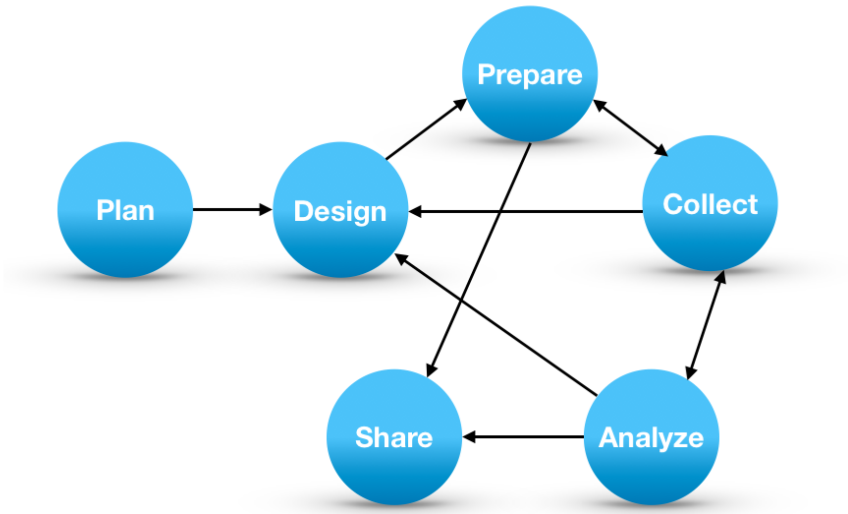


Figure 3.1: Linear iterative activities process of a Case Study Research. *Adapted from Yin [230].*

When performing a Case Study research, Yin identifies six activities; **Plan, Design, Prepare, Collect, Analyze,** and **Share**. Figure 3.1 presents the interrelations between the different activities, defining a linear but iterative process to achieve a successful Case Study.

The **Plan** activity focuses on the decision of the research method based on the research nature and question. This TFM research has the most suitable characteristics to perform the method as the research question for each company states **Why is this company considered promising or stands out from the rest in the space EO sector?** Moreover, there is no control over the behavioral events by the author, and the cases are contemporary.

The **Design** activity consists of defining the logical connections between the collected data and conclusions to the initial study question. Therefore, the vital research design components are the Case Study questions, propositions, and units of analysis, the logic connecting data to propositions, and the criteria interpreting findings. For a Case Study that is explanatory, descriptive, or exploratory, a theoretical proposition is helpful when designing, deciding on the collected data, and generalizing its findings.

Table 3.1: Case Study Tactics for the 4 Design Tests. *Adapted from Yin [230].*

Test	Case Study Tactic	Phase of Research
Construct Validity	• Use multiple sources of evidence. • Establish chain of evidence. • Have key informants review draft Case Study report.	Data Collection Data Collection Composition (Share)
Internal Validity	• Do pattern matching. • Do explanation building. • Address rival Explanations. • Use logic models.	Data Analysis Data Analysis Data Analysis Data Analysis
External validity	• Use theory in single-Case Study. • Use replication logic in multiple-Case Study.	Research Design Research Design
Reliability	• Use Case Study protocol. • Develop Case Study database.	Data Collection Data Collection

When designing, four logical tests judge the quality of the research; construct validity, internal validity, external validity, and reliability. Table 3.1 exhibits the tests, their Case Study Tactics used to accomplish them, and the research phase when the tactic occurs. The first test tries to identify correct operational measures for the studied concepts. The second test seeks to establish a relationship where conditions lead to other conditions. The third test defines the domain where the findings can be generalized. Finally, the fourth test demonstrates that the operations of the study can be repeated with the same results.

Eventually, there must be a decision on whether the research is a single or multiple-case design, and if each case is holistic or embedded with multiple analysis units [230]. Three cases (**multiple**) will compose this TFM in an **embedded** structure.

The **Prepare** activity starts with the researcher preparation, defining its skills and presenting a Case Study training. Then, he should create a Case Study protocol that contains an overview of the project, the data collection procedures, its questions, and a guide for its report [230].

The **Collect** activity sets the foundations for mastering data collection. The six available sources of data are documentation, archival records, interviews, direct observation, participant-observation, and physical artifacts. While addressing the design tests from Table 3.1, this activity introduces four general data collection principles. Those are the usage of multiple sources of evidence, the creation of a Case Study database, the maintenance of a chain of evidence, and exercising care when using data from electronic sources [230]. This researcher will follow the four principles with the challenges in mind while **documentation** and **archival records** will be the data sources. Thus, the sources could better be described as primary or secondary, depending on their origin.

The **Analyze** activity addresses the analysis of the Case Study evidence through an analytic strategy. It starts by manipulating the gathered data and searching for promising patterns, insights, or concepts. Then, four strategies are well defined, and their usage is not mutually exclusive. Those rely on theoretical propositions, working the data from the ground up, developing a case description, and examining plausible rival explanations. Once the strategy is set, five analytical techniques come up to be very useful when dealing with internal and external validity problems [230].

1. **Pattern Matching.** The empirical pattern from the collected data is linked to a known pattern, aiming high matching precision. The usage of patterns is classified as nonequivalent dependent variables, rival dependent variables, or simple.
2. **Explanation Building.** Considered as a more complicated type of pattern matching, it aims to build a case explanation through data analysis. Revision and modification of the initial statement occur as the data gets analyzed, making it an iterative process.
3. **Time-Series Analysis.** The researcher looks to match its observed trend with a theoretically significant or rival trend, defined before the research question. The identification of the specific indicators to trace over time is essential.
4. **Logic Modeling.** A match between empirically observed events and theoretically predicted ones occur in a complex chain over an extended period, repeating cause-effect-cause-effect patterns. There are three types of logic models; at individual, organization, or program levels.
5. **Cross-Case Synthesis.** Researchers perform Multiple-case analysis through a comparison of different qualitative and quantitative data.

The **Share** activity advises on reporting the Case Studies by bringing their findings and results to closure. The researcher has to identify the audience of the report in order to adapt its composition. The report can take the form of a classic single-Case Study, a classic multiple-Case Study, a single- or multiple-Case Study based on questions and answers, or a multiple-Case Study with chapters dedicated to separate cross-case issues. The composition structure can be linear-analytic, comparative, chronological, theory-building, suspense, or unsequenced. This TFM targets **academic** and more specialized **business audiences**. The composition is for a **classic multiple-Case Study** with a **linear-analytic** structure.

Yin suggested a procedure for doing the report. It is important to start composing the report early in the analytical process. Then, the researcher should evaluate the anonymity of the personalities involved in the Case Study. A review of the report draft should follow, not just by peers but also by participants or informants involved in the case. Ultimately, the investigator should always keep in mind five characteristics to make a Case Study exemplary. It must be significant, complete, consider alternative perspectives, display sufficient evidence, and engaging.

(This page was intentionally left in blank.)

4 | Spire Global Case Study

This chapter presents the Case Study of Spire Global; a US private company specialized in space-to-cloud data analytics. Spire provides the most advanced aviation, maritime, and weather tracking in the world through their satellite data and algorithms. It is possible thanks to their self-developed and owned constellation of Nanosats, a global ground station network, and continuous operations for real-time Earth coverage [28]. The information is organized under History and Overview of the company, Business Statement and Philosophy, Ownership and Employees, EO Market Segment and Requirements, Production System, Operations, Satellite Payloads and Applications, On-line Platform, Most important Partnerships, and Financial Status and Risks.

4.1 History and Overview of the company

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 CTO), Jeroen Cappaert (current CTO), and Peter Platzer (current CEO) [177] (see section 4.3 Ownership and Employees). It was the latter 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*" [45].

1. **Shrinking government budgets.** There was a need for other sectors, like the private, to step in as the government budgets were getting more and more squeezed.
2. **Billionaires in space.** They want to leave a legacy by putting their reputation, network, capabilities and net worth on the line, filling the gap left in the previous point.
3. **New technologies.** Nanosatellites are three orders of magnitude cheaper and lighter than traditional satellites, can carry the newest technology and are launched more often.

Thus, the industry was changing from a slow and government dominated to 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 Platzer to go to the International Space University and obtain an 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 started a company. Three principles established their business and remained as its main pillars; they "*collect data where nobody else can,*" they "*collect data not with the size of the sensor but the number of sensors creating value,*" and they "*collect data where the sensors are programmable and re-programmable by software to bring Moore's Law to space*" [171].

Nanosatisfi started building a Nanosatellite prototype intended to be a platform to approach space to students in terms of accessibility and costs. It was the ArduSat, based on Arduino technology. Its funding started thanks to the crowd-funding website Kickstarter [177]. With an initial goal of USD 35K to build the 1U CubeSat, the amount raised to USD 106.33K from 676 backers by the end of the funding period in July 2012. Soon after that, Spire raised USD 1.2M from individual angel and venture capital investors on the AngelList platform for start-ups, helping them build their company [12]. They moved to the hardware incubator Lemnos Labs in San Francisco and found themselves its launch pad [224].

Eventually, the 2 ArduSats (1 and X) (see sections 4.6 and 4.7) were launched from Japan to the International Space Station (ISS) on August 3, 2013. They were deployed on November 19, 2013, and reentered the atmosphere by April 2014 [132]. Due to the program's success, Nanosatisfi launched the next generation of ArduSat, the ArduSat 2, onboard the Antares-120 to the ISS on January 9, 2014. This 2U CubeSat was deployed on February 28, 2014 and reentered the atmosphere later that year [130].

The crowd-funded program of the ArduSat made Platzer gain the recognition by the Obama administration as a "Croudfunding Champion of Change" in 2013. The ArduSat 1 and X were the first-ever crowd-funded satellites in orbit [177]. However, the main idea Sparks, Cappaert, and Platzer had in mind was to develop the most accurate weather forecast, and never lost sight of that [171]. They launched their fourth satellite on June 19, 2014. The Lemur-1 is a 3U CubeSat intended for technology demonstration and EO, with Electro-optical and IR imaging payloads [131]. It was intended for meteorological, aeronautical and maritime potential commercial markets and received approval from the National Oceanic and Atmospheric Administration (NOAA). The CubeSat is still in orbit [177, 210].

On July 28, 2014, Nanosatisfi changed its name to Spire Global, 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 that raised their total fundings to USD 29M [176]. That same year Spire opened a second office in Singapore. In the eyes of Platzer, this country's government "*spends much effort to create economic diversity and economic growth, thinking about industries that do not require large amounts of people and land*" [171].

The year 2015 started with the announcement of Spire's next generation of CubeSats, the Lemur-2 (see section 4.7 Satellite Payloads and Applications). This 3U CubeSats will create a constellation that, at that time, was able to collect meteorological data though GPS-RO (Stratos) and ship-tracking data through AIS (Sense) [128]. They will provide more accurate and reliable weather predictions, and fleet efficiency, safety, voyage, and fuel management improvements for shipping companies. With an expected lifetime of two years, the Spire constellation is safe with regular technological updates. The first four Lemur-2 were launched from India and deployed on September 28, 2015. Until February 1, 2018, 77 Lemur-2 have been launched with the same configuration, with orbital altitudes ranging from 400 km to 590 km. However, starting on May 21, 2018, new CubeSats will incorporate an additional payload to track airplanes through ADS-B (AirSafe) [133].

During the 2015 summer, Spire opened a third global and first European office in Glasgow, the UK, that would support the design, development, manufacturing, and data management of the company's CubeSats. The announcement came with a GBP 1.9M grant from the Scottish Government and the Scottish Enterprise [149]. A few days later, on June 30, 2015, Spire secured a USD 40M Series B investment funding [145].

2016 brought the opening of the fourth Spire Global office in Boulder, Co. While the firm was launching the Lemur-2 and was building ground stations, the NOAA awarded Spire Global with the first-ever satellite data contract to a private company in September. Spire joined the US government in the acquisition of weather data from space to improve weather forecasts. As part of the government's Commercial Weather Data Pilot program, the house got a USD 370K award [126].

Spire finished the year announcing the space-based global aircraft tracking service AirSafe on December 6. By using ADS-B transceivers, the new Lemur-2 payload will capture and provide the location of most international flights. The new International Civil Aviation Organization (ICAO) mandate would be effective by November 2018, forcing airplanes to provide updated flight information every 15 minutes [213].

On March 6, 2017, Ball Aerospace and Spire Global announced a collaboration in association with the National Geospatial-Intelligence Agency to improve Maritime Domain Awareness in the Arctic. Spire's constellation will collect vessel tracking data over the region. It is integrated into Ball's cloud-based data analytics architecture with other external data to create accurate and near real-time information on Arctic maritime activity and vessel behavior [180].

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, in Luxembourg, will serve as the company's full-service European headquarters. The financing round was lead by the Luxembourg Future Fund, which also became a Spire shareholder. With this, Spire aims to increase access to global talent while establishing in a country that provides support, commitment, and expertise to NewSpace [179].

February 1, 2018, saw how the UK Space Agency awarded GBP 4M to the company to demonstrate space technology, including parallel super-computing. This technology must serve as a core component for future computationally intensive missions [200].

The firm made significant steps towards its satellite-based aircraft surveillance platform with two announcements in March. First, they signed a Letter of Intent with INDMEX for the use of the collected ADS-B data for airport and airline collaborative decision making [192]. Second, Spire Signed a Memorandum of Understanding (MoU) with Airbus in order to contribute with Spire's ADS-B data to the Airbus Surveillance Digital Eco-System [185].

The company saw its quality satellite development recognized and rewarded with a joint partnership with DHV Technology to offer its solar panels to the rest of the space industry. Spire would build and sell the double deployable panels [189]. More partnership announcements occurred on April 24, 2018, when Spire Global and Esri would collaborate to integrate the latter's satellite datasets into the former global user ArcGIS platform [191].

However, not everything was a piece of cake. On September 27, 2018, an NOAA Congressional Report regarding the Commercial Data Weather Pilot reviewed the program contractors in 2016's Round 1 and the delivered data. Spire Global's first dataset had quality issues in background noise, uncertainty in satellite position, and clock offsets. NOAA required them to fix the issues, but Spire submitted the improved data in the last week of the delivery period. It showed similarities with the weather model outputs but was inconsistent. The data was not enough for NOAA to make statistically significant conclusions, leading to a reduction of Spire's award to USD 87.3K. Thus, the company had to de-obligate the remaining USD 282.7K of the initial contract [218].

A few days before the Congressional Report, the NOAA awarded Spire with a contract for the program Round 2 on September 17. As in Round 1, it aimed to evaluate the quality of the weather data from the GPS-RO satellite companies but readdressed some issues found. Spire received a USD 1.425M award and had until July 31, 2019, to deliver the data [155].

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 signals to perform weather sensing radio occultation. The Galileo constellation will be fully operational with 30 satellites in 2020, enabling Spire to harvest about 25% of the GNSS-RO profiles available and making it unrivaled. The announcement also highlighted Spire's capability and flexibility to produce satellites and update their software and hardware [53].

By May 2020, Spire Global has launched 115 satellites. From those, 89 are still operational, 10 experienced a launch failure, one had a deployment failure, and 15 already reentered the atmosphere [139].

4.2 Business Statement and Philosophy

Spire Global's 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's sake - we do things that truly matter*" [52].

The *Global Trends in Small Satellites* [140] defines the organizations 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.*" This report also states Spire's goals as to "*aspire to build and operate the first commercial weather satellite network*". Platzer mentioned that three essential pillars are the company's base [171].

1. To collect data where nobody else can.
2. To collect data creating value not with the size of the sensor but with their number.
3. To collect data where the sensors are programmable and re-programmable by software to bring Moore's Law to space.

In their web page, Spire Global emphasizes on the value creation and its measurement. They define value as the "*cash flow per employee times the number of people that products affect.*" Spire thinks about it holistically, stating that a one-dimensional metric is not enough to measure value. Similarly, their Stratos and Sense products reach every part of the economy through weather and shipping, respectively. They also affirm that Spire is "*measured by impact*" and a "*data driven organization*" because "*if you cannot measure it, you cannot improve it*" [187]. Spire Global follows a Kaizen productivity philosophy in all platform business aspects, meaning a constant continuous improvement. The firm applies this philosophy to its manufacturing system to continue to evolve and embrace new technologies to further improve [20].

Platzer described Spire's unique company culture as one which differs from a traditional approach and tries to inspire people. He claims that people's needs have changed thanks to better economic environments, and nowadays, they seek autonomy, mastery, and purpose. It became a company's anchor principle, as the firm expects employees to push for excellence through relentless growth, achieving mastery. The area where workers master is self-chosen, providing an autonomy that is regularly evaluated and spurred with resources [171].

Spire website hosts a section to explain the culture of the company. They relate the purpose, mastery, and autonomy drives with how to find them at the company and how the firm encourages employees to seek them. They align personal purpose with Spire's missions and vision, measure mastery through the reliability of on-time deliveries, and encourage autonomy through ownership of employees' tasks. Instead of traditional managers, they developed a system with coaches and captains. The former are exceptional leaders who mentor their subordinates (called "*players*") through interpersonal skills to achieve others' personal growth. The latter are the technical leaders responsible for the driving results [186].

Instead of performance reviews, Spire caries out quarterly coaches' discussions to address their player's purpose, autonomy, and mastery growth [186]. This discussions involve questions such as "*how are your autonomy, mastery and purpose doing?*", "*what do you enjoy, and how to do more of that?*" or "*where do you see yourself in 5 years?*" [171].

Regarding all the above, Spire defines its people as self-driven and growth-oriented. They have a relentless desire for self-improvement, are collaborative across boundaries and timezones, and have a high emotional quotient. They recognize emotions, communicate effectively, and adapt to social changes [188].

Connected to the culture, Platzer earned a reputation of being the boss who fired no one. However, this was not entirely true as the company has zero tolerance towards employees doing inappropriate, illegal, or insubordinate actions. This policy has led to a few rare dismissals. Although the culture of the company encourages them to find a solution to align the company mission with the worker's purpose, if it is not possible, they will always agree to part ways [171].

4.3 Ownership and Employees

Spire Global claims on its website that they do not have a typical organization chart, following their personal development goal through coaches and captains. All their members work in critical business areas that ultimately support the customers at the top of the chart. The stack is distributed in a way that all its parts are crucial and must complete their goals. Figure 4.1 displays the chart, with the enumerated unit names distributed into six groups [199].

4.3.1 Coaches and Captains

Instead of managers, the company has in each stack unit somebody in charge, responsible for keeping data and communications flowing. These leaders are the Coaches and Captains, as explained in section 4.2 Business Statement and Philosophy. They are the most decisive team members of the company [199].

Peter Platzer: The co-founder and CEO was born in Austria, outside Vienna. He studied Physics at the TU of Vienna until 1996 when he started working as a strategy consultant at The Boston Consulting Group. He studied a Master of Business Administration (MBA) at the Harvard Business School, and spend a decade on Wall Street as a quantitative investment manager, building models for new markets. In 2009 he attended NASA Ames for an eight-day executive program. Instead of learning about broad trends driving global markets, he left only thinking about space. Thus, he studied an MSc in Space Science and Management at the International Space University, where he met the Nanosatisfi co-founders. He married his coworker Theresa Condor, and now they live with their daughter near the Glasgow Spire office [224, 171, 163]. As CEO, he is responsible for ALL the stack units.

Joel Sparks: The co-founder and CTO was born in Canada. At Carleton University, he obtained his BSc in Aerospace Engineering with a specialization in structures, systems, and vehicle design and worked as Research Assistant. Sparks earned an MSc in Space Science and Management from the International Space University, where he met the other co-founders. He has worked as a Mechanical Designer, Space Magazine News Editor, or Space Mechanism intern. 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 [175, 199]. He currently works at the San Francisco office.

Jeroen Cappaert: The co-founder and CTO was born in Belgium. He studied his BSc and MSc in Mechanical Engineering at the Catholic University of Leuven, performing his MSc Thesis with an internship at the Von Karma Institute for Dynamics. He has an MSc in Space Engineering, Applications, and Science from the International Space University, where he met the other Spire co-founders. While the creation of Nanosatisfi, he worked as a CubeSat and Fluid Mechanics Researcher at the NASA Ames Research Center. Since then, he is the co-CTO in charge of the Satellite Launch, CCS, Manufacturing, RF Quality, Payload, Satellite and Comms units [127, 199]. He currently works at the Glasgow office.

Theresa Condor: Theresa is the Executive Vice President of Corporate Development. She is in charge of the BMSS unit. As the wife of Peter Platzer, she lives with him near the Glasgow Spire office [224, 199].

Alexander (Sandy) MacDonald: He is the Global Validation Model Leader and Director, in charge of the GNSS-RO Product unit [199].

Marcus Tallhamn: He is the Product Engineering Manager in charge of the AIS Product, GNSS-RO Product, Data Services, CCS, and Comms engineering units [199].

Austin Ellis: He is the Maritime Sales, Customer Experience, and Satellite Operations Engineer, in charge of the Satellite Operations unit [199].

Jenny Barna: She is the Launch Manager in charge of the Satellite Launch unit [199].

Daniel Bryce: He is the Manufacturing and Operations Manager in charge of the CCS, Payload, Satellite and Comms units [199].

Nick Allain: He is the Director of Public Relations and Brand in charge of the Public Relations and Brand unit [199].

Art Fischer: He is the Ground Stations Field Engineer, and Business Operations and Facilities Manager, in charge of the Ground Stations and Office Management units [199].

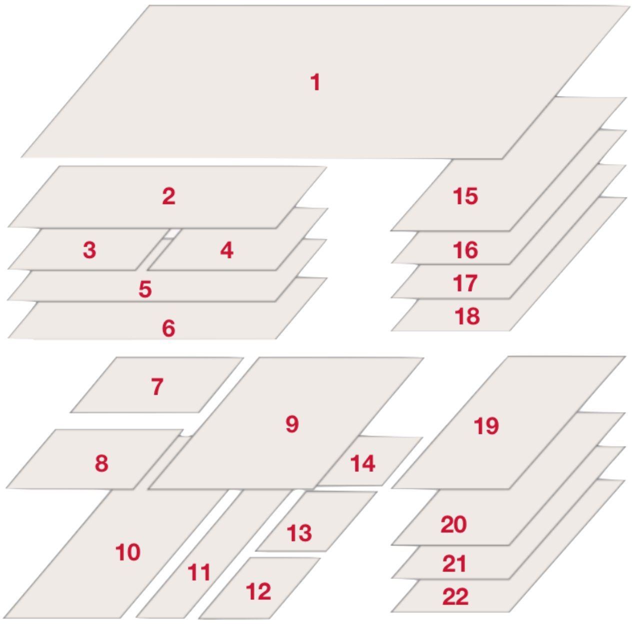
4.3.2 Employees experience

Employees can post reviews of the company in Glassdoor Inc. [52]. The posts date from September 2014 to November 2018 and help to evaluate their experiences. The ratings and trends of these 18 employee reviews show how 61% would recommend Spire to a friend, with a positive business outlook, and 71% approve the company's CEO. Reviewers had to grade five different categories, from 1 to 5. Those are the company's culture and values, the work/life balance, senior management, the compensations and benefits, and career opportunities. The average rates for these categories stand at 4, 3.8, 3.5, 3.6, and 3.7. They have been constant through time, except for the work/life balance and the compensations and benefits that have increased its rates steadily. The Overall Spire Global Rating stands at 4.

The reviewers also specify the pros and cons of working at the company. Among the pros, the most repeated topics were the incredible experience of 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 mentioned that the offices present relaxing and familiar environments full of fun people. The company offers working one week a year in any other world office with all the expenses covered, and a vacation policy of unlimited days. Spire Global organizes different leisure activities and team building workshops that help the employees to get better to know each other. Some reviewers have stated that Spire allows each employee to name a company's satellite.

Most of the disagreements between reviewers come with salaries, personal and professional growth, and reviews. For some, wages are competitive, but for others, they are not. The general view is that salaries are high for a start-up but not competitive in the sector. The company does not do individual performance reviews. Instead, the implemented coaching system generates debate. Some employees see this as an advantage as coaches help their personal and career development. However, others see this as a drawback, as the rewards system does not always award to the hard workers, and coaches seem not to care about their employees' 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 conversations but forgetting it later. Coaches have shown no coaching strategy or openness to suggestions.



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.** Comms,

15. Public Relations and Brand, **16.** Talent, **17.** Office Management, **18.** IT,

19. Legal, **20.** Finance, **21.** Supply Chain and **22.** Development Operationss.

Figure 4.1: Spire Global stack organization chart. *Adapted from Spire Global Inc. [199].*

Besides, some employees have experienced situations in which a coach suggests they take a few days off with no consequence, but when they come back, they get fired with no apparent reason.

A repeated drawback is the difficulty of the logistics of having offices in countries with different time zones. It makes employees work during free time and holidays, hindering project planning. Regarding organization, a few reviewers stated that the top levels of the firm are more focused on the space program than in building a business.

Finally, one reviewer gave the most interesting drawback exposition. This employee stated that the environment is extremely stressful and cutting-throat. The fear of being fired at any moment is fully present. The coworkers' competition is fierce, willing to subvert others' contributions and innovations. A dog-eat-dog atmosphere is plausible with public e-mail shaming and putting others down. The reviewer also points out that this is even stronger between women.

4.4 EO Market Segment and Requirements

Spire's Lemur-2 constellation collects the data that base their products. Nowadays, the firm operates in four defined market segments; advanced maritime domain awareness, critical weather data, air traffic data, and space-as-a-service (see section 4.7 Satellite Payloads and Applications). While the latter is exceptional and comes from the robust Spire value chain, the first three are directly related to the collected data. The company's interest in these markets originates in its three pillars[1]. They provide an always increasing customer value, bringing solutions with the products to five well-identified sectors; Shipping and Maritime, Government and Military,

[1]To collect data:

- Where nobody else can.
- Creating value not with the size of the sensor but with their number.
- Where the sensors are programmable and re-programmable by software to bring Moore's Law to space.

Supply Chain and Logistics, Aviation and Meteorology [22].

4.4.1 Shipping and Maritime

Spire intends to help companies monitor their ships traveling through oceans by focusing on the advanced maritime domain awareness market segment. They claim that modern maritime transport involves many players with multiple roles. Companies focus on owning and managing ships, shipbroking, chartering, or market analysis. The data to analyze 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 [197].

The Sense product has improved and predictive AIS. It blends the collected data with external for better and faster answers than other solutions. The Blue Economy[2] market opportunity, in section 2.2 The market opportunities for EO, supports this solution. Some industries interested in the product may be the Oil and Gas, Fleet Management, and the Financial Services [202].

4.4.2 Government and Military

Any public agency always seeks safe and advantageous data, as proper use of data will determine the forthcoming decades. It also helps to cope with security and stability issues that can be harassed by illegal transactions, weather, or climate disasters. This solution addresses the Security and Defense market opportunity in section 2.2 The market opportunities for EO, and the Disaster Resilience and Humanitarian Aid.

Spire offers its AIS and ADS-B data to public institutions through its Sense and AirSafe products. They help customers deal with illegal fishing, coast guarding, and aircraft identification. Moreover, the Stratos product can provide meteorologic, in-space TEC, and ionospheric characteristics data. The last two sets are crucial for the military sector because ionospheric space activity can cause detrimental effects on GNSS and radio signals, blocking positioning information, and secure communications. Finally, Spire's space-as-a-service provides a reliable space platform for agencies to install their sensor and gather customized data [195].

4.4.3 Supply Chain and Logistics

The Spire Global data sets help many data-first logistics firms tackle high-dimensional problems and bring innovation to customers. The data collected from GNSS, AIS and ADS-B payloads can be handy as the vessel and aircraft critical links compromise goods around the globe. Nonetheless, the process starts away from shores and airports, where extreme weather can affect it. Natural disasters caused an economic loss of USD 211B in 2016. Besides, over 90% of World trade was transported by sea, while 33% of US import value was carried by air [198].

[2]The Blue Economy is the sustainable use of ocean resources for economic growth, improved livelihoods, and jobs while preserving the health of the ocean ecosystem [227].

The combination of the maritime domain awareness, critical weather, and air traffic data with machine learning and Artificial Intelligence (AI) leads to better companies' decision making, increasing transparency, and reducing risks. Spire's help is present even in en-route weather risk warnings that can be efficiently communicated, mitigated, or solved [198]. This solution links with the Blue Economy and Urban Development, Infrastructure, and Transportation Management market opportunities in section 2.2 The market opportunities for EO.

4.4.4 Aviation

Spire helps aviation management optimization in safety, environmental conservation, and profitability by identifying, tracking, and predicting aircraft movements. It has massive importance as there are over 87,000 flights per day. The aviation sector generates large amounts of money in passengers and goods transport. Just in 2017, air cargo operations recorded USD 95.9B. Therefore, preventing tragedies similar to the Air France 447 in 2009 and the Malaysian Airlines 370 in 2014 flights is a sector and Spire priority [194].

Applying the new ICAO ADS-B regulations, the Lemur-2 constellation and Spire will track any aircraft globally. Thus, Spire provides the required ADS-B and weather data through their AirSafe and Stratos products to airlines, aircraft operators, airports, and partners. The data helps them optimize the profitability and environmental efficiency of their operations [194]. This solution is associated with the Urban Development, Infrastructure, and Transportation Management market opportunity in 2.2 The market opportunities for EO.

4.4.5 Meteorology

With the threat of climate change and the development of global businesses, the interest in weather and climate has risen. It daily affects every person over the planet. Spire offers global weather models that focus on reliable forecasts for people outside Europe or the US, where weather forecasts are already good. The firm is the only commercial GNSS-RO data provider in the world that increases forecast accuracy. Spire will offer GNSS-R data from late 2019, giving valuable data sets for forecasting [196].

Spire uses its cloud-based processing system to treat the sensed raw data and convert it into weather forecasts. The Stratos product serves customers with this valuable information. This innovative practices have awarded Spire NOAA contracts in demonstration projects for commercial meteorology [196]. This solution is mostly connected with the Environment and Climate Change market opportunity in section 2.2 The market opportunities for EO.

4.5 Production System

A typical space data-analytics value chain contains Satellite Design, Satellite Build and AIT, Satellite Launch, Operations, Data Sales, and Analytics. Spire Global realized early that a contract manufacturing model for AIT did not meet its requirements; it was slow and expensive. Thus, the firm owns all the chain elements except for the Satellite Launch, which subcontracts to selected partners (NanoRacks, ISIS, ECM, and RocketLabs). Figure 4.2 shows this value chain and the Spire owned elements. This approach enables more control, speed, and reliability, with the customer value and the system performance improving at every iteration loop of the product update. Altogether with decreased system costs, Spire can provide the highest quality data with the lowest risk [22].

Figure 4.2: Space data-analytics value chain with Spire's elements. *Adapted from Cappaert [22].*

4.5.1 Satellite Design

Spire bases its methodology in agile software, thinking about satellite iterations and engineering. Processes and ideas only stay if they help the company achieve its goals, welcoming fresh ideas. Spire's satellite iteration model is an example. Engineers use major update versions for backward-incompatible changes, minor for simple features and fixes, and branching to develop multiple features in parallel. The model allows adaptability, satellite improvement between iterations, and different risk levels.

The design starts with a work scope based on new feature ideas, customer requests, or needs. Engineers perform an initial mission-level evaluation to translate mission requirements and objectives into high-level satellite feature list, high-level trade-offs, and sets of budgets. They will determine mission feasibility and the platform scope of change. The satellite design team uses the evaluation results to complete a satellite deep-dive review, whose outputs are system lists of action, subsystems requirement lists, and qualification plans for both [22].

In the next stage, subsystems are designed and reviewed with qualification test reports. If there is no need for changes, engineers acquire the design flight hardware. Spire produces and carries out all the required documentation, hardware, and software tests. The following stage sees the building of a qualification model, equivalent to a future flight model, that serves to perform qualification integrated tests and will remain on Earth for future platform revisions. Once the prototype passes the tests, a Certificate of Compliance accredits it with the signature of the satellite design, manufacturing teams, and the satellite operations mission director.

Finally, the manufacturing team receives the designs, and the supply chain team collects hardware for the satellite building. They hand a list of actions to the ground systems and satellite operations teams. Then, the latter put the satellite into production.

Spire's design process is not entirely linear, containing many iterations and back-and-forth movements. Figure 4.3 illustrates the process scheme. However, Spire has cleared that the engineering team must deliver documentation as an output. They sustain that "*a brilliant idea is not useful if it cannot be communicated*" [22].

4.5.2 Satellite Build and AIT

Spire developed internal software that stores all the design, supply chain, finance, and manufacturing data. It is the main communication channel for documents and keeps all the in-orbit satellite data available. The system supports their fast iteration cycles, allows them to be lean and flexible in their engineering processes, and ensures quality and reliability [22].

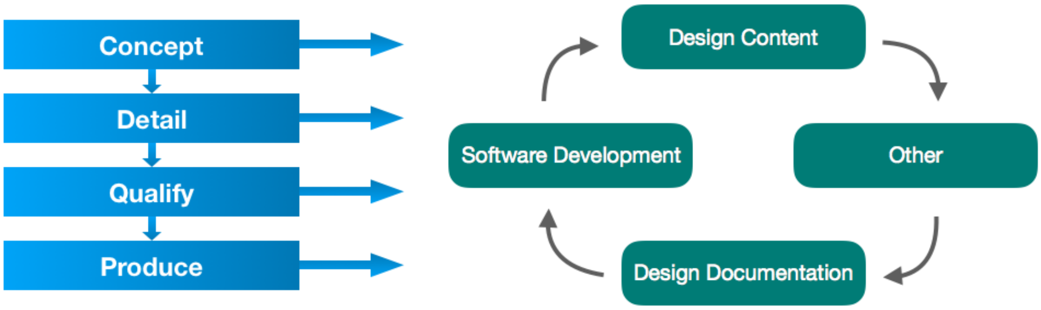


Figure 4.3: Spire's satellite design process[3]. *Adapted from Cappaert [22].*

Another reason why Spire can afford fast iteration cycles is the ownership of satellite Assembly, Integration, and Testing (AIT) teams, and their associated systems and facilities. When they receive a component, it has to undergo incoming inspections and tests. They are almost entirely automated, allowing employees to focus on the results and not the procedures. After the documentation enters the software, the components are back to the shelves. They are only picked up when a satellite has to be assembled according to schedule. Once mounted, the CubeSats undergo integrated functional and environmental testings. Then, they are ready to be launched.

Spire owns its building and test facilities, bringing many advantages. It increases their satellite build capacity and flexibility while reducing satellite-test times dramatically. It also allows engineering teams to perform better in root cause investigations, new features, and subsystem qualifications [22].

4.5.3 Ground Stations

Since the beginning, Spire saw the need to own the ground station element in the value chain (Satellite Operations). It gives them the flexibility to operate their constellations and acquire data. Additionally, the ground stations network helps them optimize their constellation contact time. As there is only a need for compatibility guaranty with their constellations, the ground stations given costs are low. However, Spire uses surge-support ground stations from partners (AWS Ground Station, Spaceflight Networks) if data requirements need it.

Spire owns over 30 ground stations across all seven continents. This network combines Ultra High Frequency (UHF) and S-band ground stations but will incorporate X-band capabilities in the future. They operate in bent-pipe mode, leaving no data unencrypted. The Spire ground

[3] *Other* refers to the activities only held in a figure left-side stage that cannot be included in any other figure right-side processes (e.g., constellation analyses and simulations at Concept stage, or the qualification-model building at Qualify stage).

stations team design, deploy, maintain, and monitor the ground stations, using a similar iterative approach than the spacecraft team for the CubeSats [22].

4.5.4 The Constant New Product Introduction Model

Spire Global defined its philosophy in manufacturing methodology as Kaizen, applying constant, continuous improvement. In the 33rd Annual Small Satellite Conference, Bryce and Cappaert [20] identified the company's four primary requirements to develop a robust but agile manufacturing process. Spire addresses these requirements with an iterative approach, considering them as a group of parallel iterations.

Define and improve the manufacturing model: Spire aimed to build about 100 satellites per year with the latest hardware available. Hence, the company needed a model with a standard process that continually changes product hardware and system software. Spire started using a "*build to launch*" model, but the latest-hardware requirement was not always possible, and there was no flexibility to transfer to another launch company effortlessly. A "*build to launch*" model added launcher flexibility, but it was a costly process in terms of resource and quality risk. The company had to use a Monte Carlo prediction model to minimize risk in prognosticating launch timing. To deliver the latest design at the right time, Spire had to place parts orders just on time. Predictions were optimistic and not very efficient. Thus, the company implemented a hybrid model, where Spire took ownership of long-lead hardware to integrate vertically and build satellite batches aligned to launchers. The ownership characteristic responds to Vertically Integrated Strategies (VIS), where a company owns many value chain elements of its business. The building starts as late as possible to allow engineering changes implementation. Spire can start the manufacturing 14 weeks before the launch, lasting for about six weeks.

Develop the manufacturing team: The company hired a Manufacturing team over the "*build to launch*" and "*build to stock*" periods to aid the rapid iteration model. It turned out to be successful as the AIT personnel was suggesting and implementing change that enhanced the building process. Spire empowered them, achieving more automated AIT activities and less data collection or documentation. Hence, this "*Deskilling of Satellite AIT*" resulted in build teams focusing on building satellites, a triplication in AIT tests over four years, and a close relation between design engineering, manufacturing engineering, and production teams. The close links between teams resulted in Spire's **Constant New Product Introduction** process, where the firm never moves to a volume environment but produces flight-ready hardware.

Design, Install, and maintain the right manufacturing facility: Spire used to rent cleanroom, RF test, Vibration test, and Thermal Vacuum test facilities. It was expensive, inflexible and compromised quality and logistics. Therefore, the firm acquired a 560 m^2 at its office location to fit it out as a 3U CubeSat manufacture and test facility. It includes an 85 m^2 class 8 cleanroom with sun simulator room and dual thermal chambers, anechoic RF chamber, thermal vacuum chamber, and Vibration test capabilities.

Enhance the integrated design and manufacturing process: Spire has standard mechanical fixtures for use in the AIT process due to the CubeSat standard design. Its automation would be cost-prohibitive, the waste of a significant resource, and would go against the Kaizen philosophy. However, automation of the control and test systems has immense value, allowing people to forget about manually creating documents, entering data, or generating reports. Spire developed in-house software, the Spire Requirements Planning, to handle all the background procedures. Those are the Manufacturing Requirements Planning, the Warehouse Management System, the Product Lifecycle Management, the Document Management System, the Factory Control Systems the Quality Systems, Issue Ticketing and resolution tracking, and the Finance Systems built-in.

These Spire's efforts resulted in cost and build-cycle time reduction and increased on-orbit CubeSat performance. Form January 2016 to May 2019, there were reductions in Materials cost by 30%, in conversion costs by 75%, and in cycle time by 45%. The company will continue to improve its manufacturing system following the Kaizen philosophy and the iteration spirit to evolve and embrace new technologies [20].

4.6 Operations

Spire Global has launched 115 CubeSats by January 1, 2020, classified in four missions, with two still active. The company focuses on its most successful project, the Lemur-2 constellation. This section explains Spire's operations, categorized in the past, present, and future.

4.6.1 Past Operations

There have been three different satellites launched by Spire (former NanoSatisfi) that are currently inoperative. They are the ArduSats -1, -X, and -2. The first two pertain to the company's first mission, while the other is from a spin-off mission of the previous.

4.6.1.1 ArduSats-1 and -X

ArduSat-1 and ArduSat-X are identical 1U CubeSats with the mission to provide an open-source platform for students and space enthusiasts. Anybody could design and try their space experiments based on the Arduino platform. As mentioned in section 4.1 History and Overview of the company, this project was crowd-funded. The satellites were deployed from the ISS by the Japanese J-SSOD at an altitude of 400 km. As typical 1U CubeSats, they weight 1 kg and have 10 cm sides. Their primary downlink occurs in UHF at 437 MHz [139].

Their central Payload/Processor is a bank of 16 Arduino processor nodes (ATmega328P) with one supervisor node (ATmega2561). The latter uploads the Arduino bootloader code from the experiments to each of the formers to run them individually. ArduSat-1 and -X get their power from solar cells and batteries and have no propulsion [173, 47, 132].

The experiment codes were developed on C or C++ language for AVR/Arduino using the ArduSat Sensor SDK software package. Engineers designed it to facilitate the interaction between developers and the ArduSat Space Kit sensors using a unified interface code [2]. This code helps the processors to sample data from the multiple satellite payloads (see section 4.7 Satellite Payloads and Applications). Both ArduSats reentered the atmosphere in April 2014.

4.6.1.2 ArduSat-2

The ArduSat-2 is an improved version of the ArduSat-1 and -X. It is a 2 kg 2U CubeSat that approaches the ISS science to everyone through off-the-shelf equipment used to collect data in space. It tests hardware and electronics intended for Earth usage at LEO, lowering the space access costs. The ArduSat-2 is very similar to its predecessors, as it bases its systems on Arduino technology and is a crowd-funded project. This CubeSat also allowed students and space enthusiasts to develop their software, but it had a more complex, developed, and established chain of software. It includes low-level assembly code controlling the sensors, C/C++ code for the onboard software and the Ruby on Rails, SLQ, or Python code for the ground and higher-levels architecture. The ArduSat-2 gains its power from solar cells and batteries and has no propulsion [162, 130].

This primary satellite downlink occurs in UHF at 400 MHz while the secondary is in S-band at 2.4 GHz. The ArduSat-2 also orbits at 400 km with 51.6° of inclination, as a consequence of its ISS deployment (see section 4.1 History and Overview of the company). 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 (see section 4.7 Satellite Payloads and Applications). The ArduSat-2 already reentered the atmosphere on July 1, 2014 [139].

4.6.2 Current Operations

Nowadays, there are dozens of operative Spire satellites in space. They pertain to two active missions, the Lemur-1 sole satellite, and the Lemur-2 constellation.

4.6.2.1 Lemur-1

The Lemur-1 is a 3U CubeSat that served as a prototype for larger satellite constellations. It is an In-Orbit Demonstration (IOD) of various payloads, aiming to introduce Spire to meteorological, aeronautical and maritime potential commercial markets. It weighs about 4 kg, and his orbit has a 612 km perigee and a 697 km apogee. Its inclination is 97.98°, and its Period lasts 97.82 min. The Lemur-1 primary downlink band is UHF at 402 MHz [174, 210].

Spire launched its fourth satellite onboard the Dnepr launch vehicle on June 19, 2014, from the Yasniy launching site at the Russian Dombarovskiy Air Base. The Italian UniSat 6 did the in-orbit deployment using a P-POD deployer. This Nanosat receives its power from solar cells and batteries and has no propulsion. The still-operational CubeSat carries two EO payloads discussed in section 4.7 Satellite Payloads and Applications [139, 131].

4.6.2.2 Lemur-2

The Lemur-2 is Spire's principal satellite constellation, composed by the Lemur-2 3U CubeSats. The name Lemur stands for Low Earth Multi-Use Receiver, as for its predecessor, Lemur-1. This CubeSats weight 4.6 kg, have no propulsion, and are powered by deployable solar cells arrays and batteries. With $10 \times 10 \times 34.5$ cm dimensions, the Lemur-2 primary downlink band is UHF at 402 MHz, and the secondary is S-band at 2.02 GHz. The firm designed, built, and operated in-house the entire constellation. These CubeSats are spread along many LEO orbits, with altitudes from 400 km to 640 km and inclinations ranging from Equatorial to SSO. It results in an almost global coverage pattern with low latencies and high revisit times [22]. Figure 4.4 shows a Lemur-2 CubeSat.

The mission objectives are to track maritime, aviation, and weather activity from space. Maritime tracking aims to solve the impossibility of tracking a ship traveling long distances because of the Earth's curvature. The ship tracking from space would increase security and safety across oceans. Aviation tracking operates similarly, providing actual location data instead of currently-used computer models predicting it in remote zones. Last but not least, weather activity tracking aims to provide weather data independently of the geolocation and altitude, with significant interest in areas where no weather stations or balloons are available (see section 4.7 Satellite Payloads and Applications) [139, 193, 18].

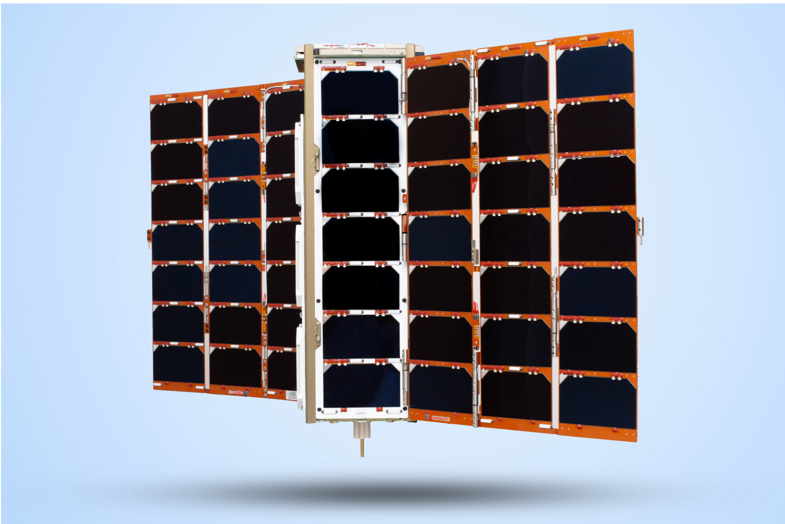


Figure 4.4: Completed Spire Lemur-2 3U CubeSat. *Image Credit: Spire Global Inc. [202].*

There have been 111 Lemur-2 satellites, from which twelve have reentered the atmosphere after being operational, and ten had a launch failure on November 28, 2017, caused by the Soyuz-2-1b Fregat-M launcher. The Lemur-2 13 Beccadewey did not deploy from the Cygnus OA-6 on June 22, 2016, and got inoperative. Therefore, on January 1, 2020, there were 88 operational Lemur-2 CubeSats. There have been six launching vehicles to bring these satellites to space on multiple occasions; the PSLV (36 units), the Atlas-5(401) (13 units), the Antares-230 (16 units), the H-2B-304 (4 units), the Soyuz-2-1a/b Fregat-M (38 units), and the Electron Curie(4 units). Once launched to space, the CubeSats have been deployed by five different deployers; the ECM 12U by ECM, the External-NRCSD, and NRCSD by NanoRacks, the Maxwell deployer by RocketLabs, and the QuadPack by ISIS [139, 133].

4.6.3 Future Operations

Spire intends to continue increasing and updating the Lemur-2 constellation. There is no official number of maximum operational satellites in the constellation, but it is believed at around 100. There are 36 new Lemur-2 CubeSats planned to be launched in 2020. New technologies and payloads are continually being incorporated in the CubeSats, while older Lemur-2 become obsolete and inoperative. 34 Lemur-2 already count with the ADS-B payload, introduced since March 2018. Furthermore, the new GNSS-R service was introduced during the third quarter of 2019, requiring improvements in processing and GNSS receivers (see section 4.7 Satellite Payloads and Applications) [139, 133].

4.7 Satellite Payloads and Applications

This section reviews the payloads of Spire's satellites and their applications as products or services. Nowadays, the company only focuses on the Lemur-2 constellation, so its related topics will have greater importance.

4.7.1 Payloads

The following sections exhibit the payloads mounted on all Spire Global CubeSats.

4.7.1.1 ArduSats-1 and -X

The identical ArduSat-1 and Ardusat-X incorporated multiple sensor payloads, in addition to the main processors. By using the students' developed code, the processors accessed the sensor payloads and obtained their sampled data. The list below summarizes the sensor payloads [154].

Optical Camera (C439): It is a single 1.3 MPx Complementary Metal-Oxide Semiconductor (CMOS) module built by SICUBE.

Optical Spectrometer (Spectruino): It is a single device designed to work with Arduino in a wavelength range from 400 nm to 760 nm, built by MySpectral.

Luminosity Sensor (TSL2561): This Adafruit Industries 2-sensors device converts IR and visible light to digital signals, and is placed beside the camera and spectrometer.

Geiger Counter (LND 716): This LND 2-sensors device monitors the radiation environment of the satellite detecting gamma rays.

Digital Temperature Sensor (TMP102): It includes four low-power sensors with 0.5 °C accuracy. Built by Texas Instruments, it tracks internal and external temperatures.

IR Temperature Sensor (MLX90614): It is a single wide-range sensing device able Earth's emissivity, and built by Melexis.

Accelerometer (ADXL345): It is a single low-power, highly-sensitive, 3-axis digital device capable of tracking the satellite acceleration. Analog Devices builds it.

Gyroscope (ITG-3200): It is a single 3-axis digital gyro. Compact, robust, and sensitive device that senses satellite movements and is built by InvenSense.

Magnetometer (MAG3110): It is a single, digital, small, and low-powered 3-axis magnetometer able to measure the Earth's magnetic field. Freescale builds it.

4.7.1.2 ArduSat-2

The Ardusat-2 incorporates similar payloads than the -1 and -X versions, but Spire updated them. The central premise to select the payloads was to be Consumer-Off-The-Shelf (COTS) systems capable of performing specific applications in space. Thus, the technology engineered for Earth use is brought to space with much lower prices due to their mass production. Multiple standard and complex sensor payloads compose this CubeSat. The standard sensors are magnetometers, accelerometers, gyros, and temperature sensors, while the complex sensors are Geiger counters, a camera, a spectrometer, and a VHF radio beacon receiver.

All the sensors are connected using an augmented Inter-Integrated Circuit (I2C) protocol. A supervisor processor communicates with the multiple Atmel chips microprocessor payload through a proprietary communication protocol, putting the individual computational nodes of the payload under rigorous control. Most of the bus components are standard spaceflight hardware, with a Technology Readiness Level between 8 and 9 [130].

4.7.1.3 Lemur-1

The Lemur-1 incorporates diverse technology demonstration payloads. Also, it carries 2 EO payloads, an Electro-Optical, and low-resolution IR imaging systems. The former is the primary EO payload and operates in the visible light band with almost 5 m ground resolution. The latter is the secondary EO payload and has a ground resolution of roughly 1 km [174, 131].

4.7.1.4 Lemur-2

The Lemur-2 constellation satellites have the objectives to monitor the weather and track global maritime and aviation activities. The payloads to do so are a GPS/GNSS receiver, and AIS and ADS-B transceivers. Furthermore, the CubeSats incorporate an Attitude Determination and Control System (ADCS), communications systems, and customized, experimental, or IOD payloads if ordered. However, not all the payloads are in all the constellation CubeSats. While all the Lemur-2 have the GPS/GNSS and AIS devices, only the satellites launched after May 2018 incorporate the ADS-B payload [133, 193].

GPS/GNSS receiver

Spire aims to reach weather monitoring with global coverage, consistency, reliability, and cost-effectiveness. Traditional weather satellites are diminishing due to technology obsolescence, resulting in inaccurate, unreliable, and long-term meaningless forecasts. Weather balloons and ground stations are better options than those satellites, but they lack global coverage.

The GPS/GNSS receiver is capable of Global Positioning System Radio Occultation (GPS-RO)/Global Navigation Satellite System Radio Occultation (GNSS-RO). This technique implies the occultation of geospatial satellite signals by an LEO satellite. The signals have to travel through the atmosphere, suffering refraction, and time delay, as observed in Figure 4.5. The angle of refraction depends on the air temperature and water vapor content. As geospatial satellite signals pass through various atmosphere levels, the receivers can sense relevant weather data. During a radio occultation event, satellites process bending angles, refractivity, and dry temperature profiles as a function of altitude, that after manipulation give high-precision profiles of the atmosphere's pressure, temperature, and humidity. These receivers can track GPS, Galileo, GLONASS and QZSS geospatial satellite signals [18, 178, 190].

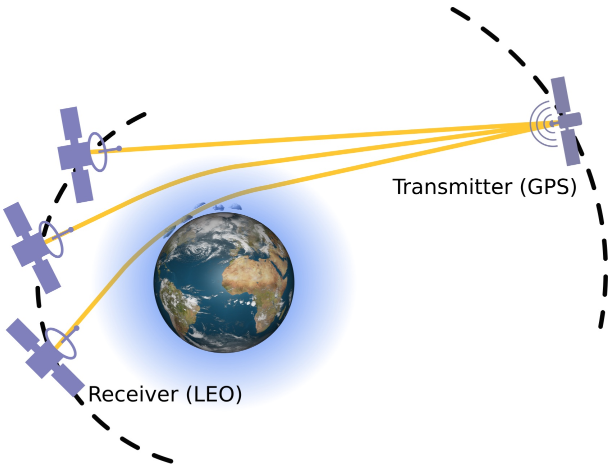


Figure 4.5: GNSS-RO and GPS-RO diagram. *Image Credit: Earth Observation Data Centre for Water Resources Monitoring [31].*

In addition to the GNSS-RO capabilities, the GNSS receivers can help the ionospheric Total Electron Content (TEC), the ionospheric Scintillation Indices, and provide Global Navigation Satellite System Reflectometry (GNSS-R). A linear combination of dual GNSS frequency phase measurements computes the TEC in each GNSS signal post-processing. The Scintillation Indices show ionospheric turbulence in the upper atmosphere. It can jeopardize GNSS receivers, losing robust and accurate positioning and timing, and leading them to loss-of-lock. The indices are calculated with the measurement and combination of the scintillation's amplitude and phase. Finally, the GNSS-R signal transmission as passive bistatic radar signals to measure Earth's surface properties. They estimate surface roughness, wind speed, heights, and ice extent maps over the sea, and soil moisture and flood inundation/wetlands extent maps over land [190].

AIS receiver

Maritime vessel tracking in the offshore ocean is impossible for land-based stations. The Earth's curvature blocks the communication signals after the distance between each other is over 50 NM. Maritime tracking is crucial for the world's economy since over 90% of global trade transits the oceans [18].

Each Lemur-2 incorporates an Automatic Identification System (AIS) receiver for communication with ships. This system has been mandatory since 1974, allowing vessels to communicate through VHF messages with their identification, position, course, and speed. 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 with enhanced coverage of remote areas, shown in Figure 4.6. Hence, satellite AIS's primary advantage is global coverage, while terrestrial's is notably low latency. Usage area examples are oceanic and Arctic regions [128, 183].

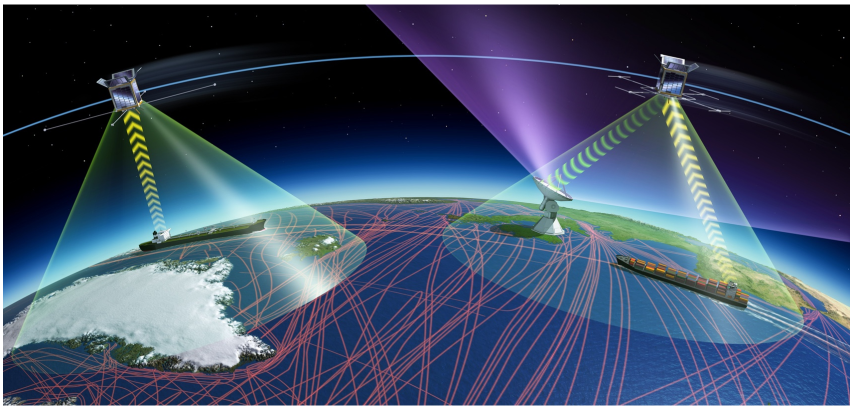


Figure 4.6: AIS diagram of global ships linking. *Image Credit: Artes - ESA [15].*

ADS-B receiver

Similar to the maritime sector, aviation has a critical need for global flight tracking. The tracking system has been mostly radar-based from the ground. This sector accepts vast coverage gaps, especially over oceans and remote areas. The Automatic Dependent Surveillance-Broadcast (ADS-B) uses GPS signals to determine airspeed, location, heading, and other information about aircraft to track them. Its transponder in the aircraft sends signal beacons to other ADS-B receivers containing the aircraft information. These receivers are either ground stations or in another aircraft. However, the land-based stations present issues with range and costs. The Line-Of-Sight range of communication is about 150 NM without obstacles, while a new terrestrial ground station can cost up to USD 12M, including maintenance [18, 43].

Space ADS-B solves the ground station issues. The satellite receivers capture aircraft signals in space to later broadcast them to a ground station network. All the aircraft data is transferred to a cloud infrastructure network where aviation authorities and operators have access. Figure 4.7 graphically supports this explanation. Combining ground stations around crowded areas with satellites in remote ones provides enhanced results. The satellites improve situation awareness and lower infrastructure costs, bringing more security, reliability, and long-term savings [43, 182]. Only the Lemur-2 satellites launched after May 2018 incorporate ADS-B receivers.

ADCS Magnetometer

Besides its principal orientation functions, the Attitude Determination and Control System (ADCS) can collect the Earth's magnetic field through its magnetometer using magneto-inductive technology. It gives high-performance resolution and repeatability with ample rates, significant gain, low hysteresis, and no temperature calibration needed. Its time resolution can be either 4 Hz or 0.1 Hz [190].

4.7.2 Applications and Products

Spire Global operates in four market segments; advanced maritime domain awareness, critical weather data, air traffic data, and space-as-a-service. The firm satisfies the first three segments with the Sense, Stratos, and Airsafe products, based on the Lemur-2 constellation collected data. The last segment leverages all the elements in Spire's space data-analytics value chain built over

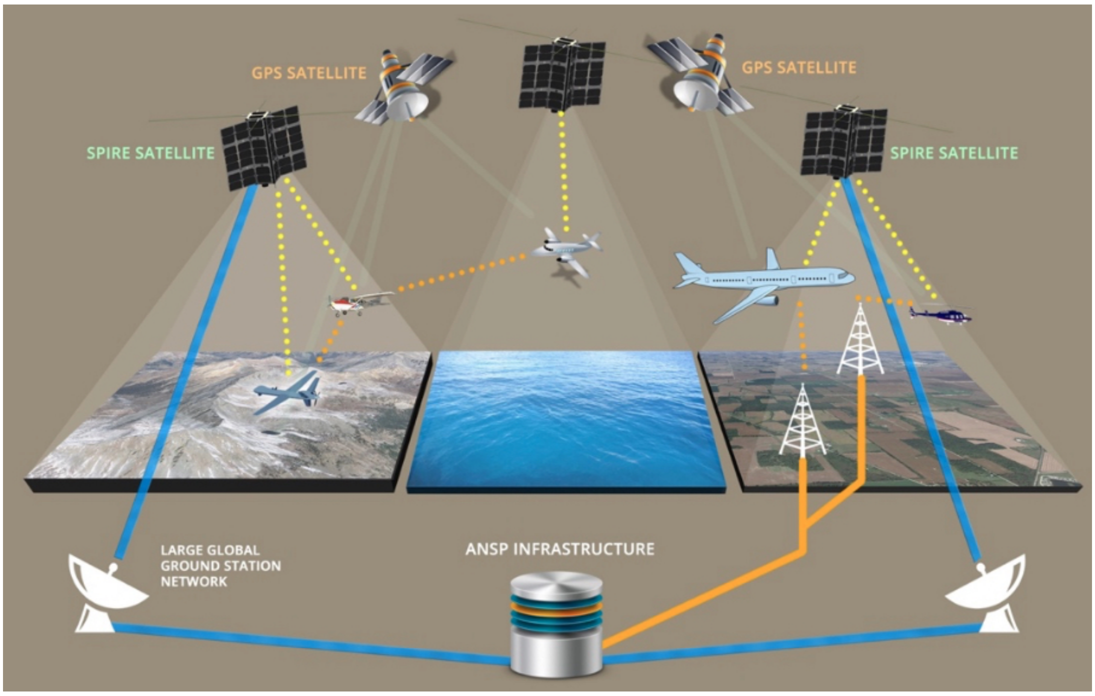


Figure 4.7: ADS-B signals diagram between aircrafts, satellites and ground stations. *Image Credit: Fernandez and Preston [43].*

the years (see section 4.5 Production System). The only element that Spire does not own is the satellite launch, which is operated by selected external partners [22].

4.7.2.1 The Sense product

The Sense product is based on AIS data from the Lemur-2 CubeSats. It aims full maritime awareness through ship tracking. Spire's system processes and cleans the data, including the attachment to vessel identifiers, and the combination with other ship information. The system creates a global coverage database of ocean-going vessels that gets enhanced with AI software. This database is updated every 15 min, contains over 400,000 ships, covers 120,000 vessels per day, and its AI software predicts vessels positions up to 8 h forward. The Sense craft data includes their IMO and MMSI identifiers, type and size, commercial owner, current and historic Lat/Long coordinates, draught, speed, heading, and departure and destination ports [190]. Figure 4.8 illustrates the AIS and ADS-B global data gathered for the Sense and AirSafe products over three months. It shows the tracks of the monitored ships in blue and aircraft in red.

Interested contractors might be mining, supply chain, financial trade, security or surveillance companies, port operation facilities, ship traders, brokers, intelligent data platforms, or governments. The latter may want to acquire Sense thanks to its capability to support the identification of transshipment, illegal movement of goods, and illegal fishing [212].

Spire provides the Sense product through an Application Programming Interface (API) that empowers users to take advantage of the vessels acquired data. The API functions through a modern developer-enabled interface. It can handle route efficiency, emissions planning, and raw commodity cargo-estimation solutions in large scales. Spire offers thee Sense monthly plans; "*Base*" for USD 5000, "*Standard*" for USD 6000, "*Premium*" for USD 9000, and "*Enterprise*" that

Figure 4.8: Global AIS and ADS-B data after 3 operational months. *Image Credit: Spire Global Inc. [202].*

requires contact to the sales team. The "*Base*" is suitable if raw undecoded AIS data is needed, while the "*Standard*" and "*Premium*" are similar, adding extended high traffic zone coverage and online data display. However, the "*Premium*" plan includes a vessel property database, prediction algorithms, and a cargo database for the following year quarter. The "*Enterprise*" plans adds to the "*Premium*" more customization and access to over 250 users. It comes with the ESRI ArcGIS infrastructure, while it has to be bought aside in the "*Standard*" and "*Premium*" plans [202].

4.7.2.2 The Stratos product

Stratos is the Spire product based on meteorological data from the Lemur-2 CubeSats, providing data from the Earth's atmosphere, ground, oceans, and magnetic field. The data includes the temperature, pressure, and moisture vertical soundings through the atmosphere. It is acquired using the GNSS-RO technique, the estimated ionospheric TEC, the ionospheric Scintillation Indices, and the Earth's magnetic field. Since Q3 2019, Stratos provides estimations on roughness, wind speed, and heights (altimetry) over the sea surface, ice extent maps over oceanic regions, and soil moisture and flood inundation/wetlands extent maps over land surfaces [204].

The GNSS-RO measured data is outputted in a BUFR binary format file from the World Meteorological Organization. This data includes precise orbit determination, LEO attitude, and BUFR atmospheric retrievals files. The first determination process aims to track the satellite position and velocity using GNSS accurately. GNSS-RO data has global coverage, a vertical resolution of 100 m, and a temperature accuracy under 1 °C. The ionospheric TEC and scintillation indices have global coverage and 1 s time resolution.

The GNSS-R data sets are presented in NetCDF files. Its measurements bring better spatial resolution and faster temporal repeat times than traditional point measurements. The

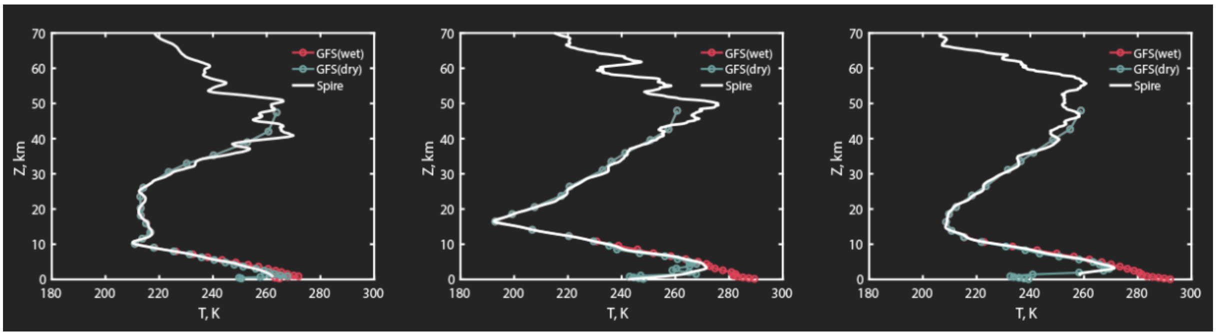


Figure 4.9: 3 Stratos profiles of temperature (K) against the altitude (km) for collected data, dry and wet Global Forecast System models. *Image Credit: Spire Global Inc. [190].*

reflectometry has a spatial resolution of 1 km over land and sea ice and 20 km over offshore seas, and a temporal resolution of 1 son the track sampling, with continuous sub-daily temporal repetition. The data includes surface normalized bistatic radar cross-section, ocean mean square slope (L-band Limited), sea surface wind speed, sea ice extent maps, surface reflectivity, soil moisture, and the flood inundation and wetland extent maps [190].

Stratos is available for maritime, aviation or agriculture weather. Each solution can be purchased in a "*Base*", "*Standard*", "*Premium*" or "*Enterprise*" plan. They combine Weather and Time Bundles, Coverages, Data Usage and Delivery depending on the plan and the type of solution [204].

4.7.2.3 The AirSafe product

The ADS-B payload of the Lemur-2 satellites acquires data for the AirSafe product from commercial, military, business, and personal aircraft. It can improve operations through increased air-traffic visibility and will replace ground stations in remote regions with better cost-efficiency. Moreover, AirSafe incorporates an optional weather data enhancement, through sharing data with the Spire's Stratos product.

The AirSafe service status is operational, with the results from the downlinked data showing that the satellite's performance exceeded expectations. Spire is currently persuading businesses to integrate AirSafe through personal private contact. It helps the company develop its technology through test aircraft while clients get promises of more satellite launches and better AirSafe future performance. Therefore, Spire announced a reselling partnership with the Japanese ITOCHU Corporation for the ADS-B data package in Japan and the rest of the Asia-Pacific region [190, 184].

The global coverage platform provides aircraft with full flight profile observation and some information. Figure 4.8 shows the AirSafe flight profiles for data gathered during three months of 2018, along with Sense data. The data contains the aircraft identification or ICAO address, speed over ground, vertical rate, latitude, longitude and height coordinates, barometric altitude, GNSS height, target state, and the operational and emergency status [190]. Spire offers 2 plans; ADS-B only from satellites or a satellite and terrestrial data integration. Both have global and regional coverage, and include flight tracking datastream and historical API. The prices of both plans can only be obtained after contacting the sales team [184].

4.7.2.4 Spire Orbital Services

Spire offers a space-as-a-service product focused on cooperation with businesses 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 can orbit any LEO inclination. In order to acquire this service, a personal inquiry to the company is needed [203].

4.8 On-line Platform

Spire Global owns its entire data value chain. The sensed information is downlinked to a ground station network located around the world (see section 4.5 Production System). An automatized software help optimize satellite-to-ground communications for better performance. The data is then processed through an analytics system and stored in the cloud, depending on its type. Finally, Spire delivers it to the customer [22].

The data can reach clients in raw files if they already have a visual layer to display it, or together in a tool to filter and organize the information. The second option generates more interest among companies that requested Spire products. Spire has partnered with companies such as Esri and MapLarge to provide data visualization tools and Geographic Information Systems (GIS). With them, customers can manage the amounts of data they want to process. GIS accepts inputs from many remote sensing techniques, selects the critical data, and organizes it into maps for analysis. If the Esri and MapLarge solutions are not suitable for customer needs, Spire encourages them to reach out to the company and explain more carefully their visualization needs, so a collaborative visualization solution emerges [181].

Spire gives client programmers access to its Application Programming Interface (API). They can modify and request actions in the cloud data. So far, Spire has developed only the Messages and Vessels API from the Sense product, but data from other Spire products will similarly reach clients. The API requests the data to the cloud, which is delivered in the stated ways.

The visualization platforms that Esri and MapLarge offer are more sophisticated versions of Spire's API. Their interface is customer-friendly with GIS global maps displaying the data. However, it is an intermediary between Spire's API and the customer, illustrated in the Esri platform GeoEvent. It needs to set a connection with Spire's API to update AIS messages and vessel features, learning their history, and creating heat maps of ship activity [201].

4.9 Most important Partnerships

Partners are vital in some areas of Spire's value chain, as well as in their development. The only chain element that the company does not own is the satellite launching. However, other areas benefit from partnerships with the most well-regarded and forward-thinking sector companies. It is the case of the ground station network and product development. Moreover, Spire has sealed many partnerships with multiple intentions.

The **ESA** is Spire's most valuable partner, as the space agency plays a key role in the firm's technology development. It started with the GBP 4M award of the ARTES Pioneer program that funds the demonstration and validation of advanced technologies in space, aiming commercialization in the public or private sectors [200]. They were planning to bring space-as-a-service to the world. Later, both parties teamed up again, permitting Spire's Lemur-2 constellation to use data from the Galileo satellites. This deal can be worth for Spire up to USD 2.7B over the next 25 years, and is crucial for the Pioneer mission objective, validating Nanosats for space-based GNSS-RO [53].

The partnership Spire sealed with **ESRI** in 2018 is very valuable as the cooperation leads to the creation of powerful and effective GIS Spire will help develop and support the ArcGIS platform, which easily integrates datasets from the Lemur-2 CubeSats. This partnership is focused so far on the maritime industry but may extend to the rest of Spire's datasets [50].

4.9.1 Satellite Launching

The versatility and size of the Spire's Lemur-2 CubeSats permit them to be launched and deployed from multiple systems. Hence, many partner companies have been involved in these tasks, depending on the intended satellite altitude and orbit. Spire usually closes a deal with a deployer company, which at the same time negotiates the rocket launching with another company. Among the deployer companies, one can find **ISIS, ECM, RocketLabs** or **NanoRacks**. Spire does not stick to a sole firm because of the still constrained launch environment. Smallsat operators should be flexible when bringing their satellites to space, keeping an agnostic and opportunistic profile towards launching providers.

The company signed a contract with **NanoRacks** to deploy four Lemur-2 CubeSats on March 30, 2019, including Spire's 100th satellite, from the Indian PSLV rocket. They signed this contract because this rideshare company carried the first-ever batch of Lemur-2 satellites to space and was a reliable contractor. The 37 previous satellite deployments via NanoRacks happened from both the ISS and the Cygnus Spacecraft. Thus, new deployers had to be manufactured, that emerged from the cooperation between NanoRacks and Astrofein [153, 123].

4.9.2 Ground Stations

Spire owns a ground station network of over 30 stations (see section 4.5.3 Ground Stations). However, they teamed up with **Amazon Web Services** to use their new AWS Ground Station service. They will construct 12 ground stations by mid-2019 with a pay-per-use basis. Spire's needs for downlinking data vary depending on countless factors. With the AWS service, Spire can instantly extend or overlap coverage on-demand with no additional hardware expenses. Eventually, with AWS ground station number increasing, Spire could remove the high costs of building and maintaining a ground station network and rent their capacity on-request [167].

The firm has also commercialized its ground station network to other companies. In a partnership with Spaceflight Networks in 2015, Spire offered ground services to this cost-effective satellite communications and data services company, expanding its global connections [148].

4.9.3 Products Development

Many companies have inked partnership contracts to develop their products. Spire's most advanced product is Sense, while Stratos and AirSafe remain in early stages (see section 4.7.2 Applications and Products). The cooperation usually occurs at the point of analyzing or presenting the acquired data.

The Sense product is based on AIS technology to track vessels around the world. In addition to the partnership with Ball Aerospace and the National Geospatial-Intelligence Agency to improve arctic maritime traffic (see section 4.1 History and Overview of the company), Spire has sealed other Sense partnerships.

- **ICEYE** teamed up with Spire Global to enable global monitoring of dark vessels, combat illegal fishing, and transshipment at sea [124].
- **CSST** partnered with Spire to provide AIS technology throughout the South Pacific Ocean. It will improve maritime situational awareness, with potential users being the New Zealand government, military, and port authorities [229].
- Together with **AXSMarine**, the company provides enhanced maritime intelligence services, including ownership, predictive, and historical vessel data [120].

The AirSafe product is based on ADS-B technology to track and communicate with aircraft worldwide. Besides the **INDMEX** and **Airbus** partnerships (see section 4.1 History and Overview of the company), Spire is working with **GE Aviation, Inmarsat** and **MapLarge** to bring flight analytics and global weather updates to the flight deck. It would integrate GE Flight Data Analytics with Spire's precise weather and ADS-B data on a MapLarge platform.

The most exciting Spire's partnership regarding the Stratos product is with the NOAA. This cooperation started in 2016 and, even though it did not end up as desired, both parties rejoined in 2018 under a new contract.

4.10 Financial Status and Risks

Spire Global is a privately held company that started hitting up backers on Kickstarter in 2012. Institutional investments preluded fundraises in Series A, B, C, and D rounds. Table 4.1 exhibits all Spire investment funds, who has raised almost USD 200M through eight years. However, as Spire Global is a private company, it is illegal to clarify whether the company plans another funding round [123].

The Scottish Enterprise awarded its grant in June 2015 when Spire opened its third global office in Glasgow. Similarly, Spire opened its fifth world office in Luxembourg in November 2017 while the Series C funding round was lead by The Luxembourg Future Fund. These fundings rewarded Spire's new offices in their respective regions [149, 179].

Spire's balance sheet can only be disclosed partially as a direct consequence that the company is private. Therefore, online sites estimate Spire's annual revenue in USD 2M [28, 158]. However, Spire's 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*" [123].

Table 4.1: Spire's investment funding rounds data [28, 158].

Round	Date	Amount (USD)	Investors (Lead Investor in bold)
Crowdfunding	Jul 2012	106K	-
Seed	Feb 2013	1.2M	Shasta Ventures, Fresco Capital E-Merge, Lemnos VC, Beamonte Investments
Seed	Jul 2013	300K	Grishin Robotics
Seed	Jul 2013	250K	Empiricus Capita
Seed	Oct 2013	750K	Empiricus Capita
Series A	Jul 2014	25M	**RRE Ventures**, Mitsui Global Investment, Promus Ventures, E-Merge, Lemnos VC
Grant	Jun 2015	2.9M	Scottish Enterprise
Series B	Jun 2015	40M	**Promus Ventures**, Bessemer Venture Partners, RRE Ventures, Jump Capital, Lemnos VC
Series C	Nov 2017	70M	**The Luxembourg Future Fund**, Seraphim Capita, Empiricus Capital
Grant	Sep 2019	18.24M	**Scottish Enterprise**
Series D	Sep 2019	40M	**Mitsui, ITOCHU, GPO Fund**, RRE Ventures, Seraphim Capital, Qualcomm Ventures
Total	-	198.74M	-

Spire's last Series D funding round opened the door for a public offering. After the round, Platzer said that the firm is not yet cash flow positive but profitability will get to Spire after the Series D. He also stated that the board members already have outlined goals and a timeline for an Initial Public Offering in about 2 years [168].

4.10.1 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. As Spire Global is private, the information on how the company mitigates these risks is unavailable. However, their description and possible impacts are presented [107].

- The **credit risk** is when a counterpart does not meet its financial obligations under a contract, leading to a financial loss. Spire could be vulnerable to it with partners such as CSST, ITOCHU, or other interested parties in its Space-as-a-service offerings.
- The **interest risk** arises when the company takes a loan. It is unknown if Spire has loans, but proper interest monitoring may lead to limited effects on the resulting finances.
- The **foreign currency exchange risk** appears because the firm operates worldwide. Spire sales, costs, and expenses may be in USD, EUR, GBP, and SGD due to their offices' locations. Thus, changes in foreign exchange rates may be significant.
- The **liquidity risk** regards the lack of funding and sufficient financial liquidity to meet

short-term financial demands. Liquidity is vital to develop and expand the business. Good management of funding and constant maintenance of cash assets will reduce this risk.

The company also has to manage other risks that may not be related to the company but would affect Spire's business, financial position, or future results [107, 205].

- The **execution risk** is tangible for Spire as the increase of production volume comes inherently with a risk of underperformance. They have succeeded so far in the production ramp-up and seems to keep growing correctly.
- The **launch of the satellites** could constrain Spire's ambitious constellation. The firm is vulnerable to the launching sector because it does not own this element. Costs and availability could reduce their CubeSats launchings with adverse economic effects. Launching malfunctions are high-probable factors that could lead to satellite losses.
- The **market competition** inside the Smallsats sector may threaten Spire's market share. Competitors develop new technologies and products, so a failure in innovative solutions may lead to a loss of offers and market share. The rising demand for LEO-based services has grown the number of adversaries, which may cause prices and quality competition.
- This **new and emerging market** could see competition from other developed sectors, threatening the market. The value proposition and technologies from other sectors like large satellites, terrestrial, and airborne platforms could stagnate or eliminate the Nanosatellites market. Spire may have to compete in fields such as price.
- The company **customers** could generate a risk if there are not enough contracting Spire's services. Hence, payment losses could lead to financial instabilities. However, Spire seems to have a good market share.
- Keeping customers and getting more can be thanks to the **products' quality**. A lousy development of Spire's products, or a lack of service quality, may lead to the inability to meet market expectations and an eventual adverse impact.
- **Key personnel** is essential in a technology company like Spire. If the company cannot retain or replace skilled personnel, ongoing projects, and development plans may be interrupted with negative consequences for Spire.

5 | GomSpace Case Study

This chapter comprises the Case Study of GomSpace. With the parent company being GomSpace Group AB, they provide turn-key solutions for space-based business, developing and commercializing COTS payloads and platforms in the Nanosatellites sector. Based on advanced radio technology, GomSpace solutions include Internet of Things (IoT), communications, tracking, surveillance, and remote sensing [151]. This chapter covers the History and Overview of the company, Business Statement and Philosophy, Ownership and Employees, EO Market Segment and Requirements, Satellite Payloads and Subsystems, Platforms and Services, Production System, Operations, Most important Partnerships, and Financial Status and Risks.

5.1 History and Overview of the company

A group of three entrepreneurs established GomSpace on January 1, 2007, in Aalborg, Denmark. Lars Alminde, Karl Kaas Laursen, and Morten Bisgaard were Ph.D. students at Aalborg University, where their experience in research and development set the company foundation. Before GomSpace creation, these entrepreneurs worked in different CubeSat projects, such as the European AAU-CubeSat, the AAUSAT-II, SSETI-Express, and Baumanetz. The firm's name comes from their student years when they were known as the "*Grumpy Old Men*"(GOM) in academic circles because of their critical, enthusiastic, and analytical approach to technology. Their entrepreneurial spirit and the dream to "*put something into space*" drove them to become the world's first initiative takers for Nanosat missions [107, 77].

GomSpace was a commercial internationally-recognized provider of Nanosatellites, subsystems, and adjacent services since its creation. NOVI Innovation partially owned GomSpace and gave them their first headquarters at the Novi Science Park. The first company projects focused on research with customers in the academic and science sectors, with the first hardware products delivered in 2008. GomSpace's development ran in parallel with the CubeSats sector. By 2010, the firm started to investigate air traffic monitoring capabilities, and in 2011 it delivered its first integrated Nanosat platform [205, 76].

The most significant milestone achieved in 2013 was the launch of GomSpace's first satellite, the GOMX-1. This IOD 2U CubeSat accomplished its objectives of air-traffic monitoring through an ADS-B receiver based on Software Defined Radio (SDR), other subsystems (NanoCam C1U), and system software [33]. At this point, the company had ten employees working for customers around 30 countries [76].

The rapid development of the Nanosats sector and its commercial opportunities become the reasons behind the GomSpace strategy shift in 2014. The company left its start-up phase and entered a growth phase with a new business focus. A renewed long-term vision embraced industrialization, aimed company consolidation, and set the foundations for future large-scale production. Hence, the business signed an experienced CEO, in Niels Buus as managing director. Nevertheless, during the same year, the company's second satellite mission could not get in orbit due to a launch failure of the cargo vehicle. The GOMX-2 2U CubeSat objectives were to evaluate components in-space such as new generation SDR or a high-speed transceiver [129].

Their third Nanosat was successfully launched in 2015. The GOMX-3 3U CubeSat was a collaborative mission with the ESA that began in 2014. It exceeded all expectations at its reentry in 2016, after the IOD of second-generation ADS-B and geostationary satellite telecommunication through an improved reconfigurable SDR. It also included a third-party payload in a miniaturized high-data-rate X-band transmitter from Syrlinks [34]. GomSpace reached the yearly 1000 CubeSats subsystems delivered mark for the first time in 2015 [70].

2016 was a pivotal year for GomSpace development. On June 16, the company entered the Nasdaq First North Premier in Stockholm, following the founding of GomSpace Sweden. It provided GomSpace additional capital and strengthened its position in the sector. The firm started projects based on their expertise in contracts to deliver satellites for ships and airplanes traffic surveillance in the arctic for the Danish Defence, and in near-equatorial regions for Aerial & Maritime Ltd (A&M). The latter would become the Group spin-off company. GomSpace also agreed to provide radio platforms and antennas for the HawkEye 360 Pathfinder mission. Finally, Aistech Space received a full CubeSat platform from the company as part of their plan to set up a network of 25 CubeSats capable of asset and aviation tracking, bidirectional communication, thermal imaging, and position management. It should be fully operative by 2020 [114].

The Initial Public Offering came with positive growth consequences. The Group acquired NanoSpace AB, adding satellite propulsion systems to its portfolio. This acquisition from the Swedish Space Corporation strengthened the GomSpace market position in Sweden and their participation in ESA funded projects. Aiming to facilitate its customers' access to launch services, the firm opened a new subsidiary in Denmark, GomSpace Orbital ApS. The Group also increased the ownership of its subsidiary A&M to 47.3% based on the contract of CubeSats at low-inclination Equatorial orbit. GomSpace would design, deliver, launch, and commission this 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) [115].

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 to 176, 99 more than the previous year. The management team gained experienced people to handle the growth challenge. They impulsed the parent company change of name from "GS Sweden AB" to "GomSpace Group AB" and the opening of three new subsidiary offices in Singapore, the US, and Luxembourg. The first two offices will help operate the company's activities in their continent markets through GomSpace ASIA Pte Ltd and GomSpace North America LLC. GomSpace Luxembourg SARL comes from a partnership with the Luxembourgian government to offer services of satellite constellation operations, data processing, and distribution. The office must count with 50 workers by 2021.

GomSpace headquarters experienced an update with a new 6,500 m^2 office in Aalborg, Denmark. It aims to develop a new production area capable of manufacturing "*one satellite a day.*" Regarding its sped up expansion, GomSpace issued 1.75 M shares to strengthen its financial position in a short time-frame. The private placement resulted in SEK 95M from a selection of institutional investors. Besides, another economic injection arrived in a grant from the Innovation Fund Denmark. The DKK 2.5M contract aims to develop a constellation management system and new radio components to improve broadband constellation communication [103].

In February 2017, the company sealed a procurement agreement with Sky and Space Global (UK) Ltd to develop and deliver a constellation of 200 CubeSats. The 4-year-period delivery agreement starts in 2018 and is valued between EUR 35M and EUR 55M. A similar framework agreement occurred with already-customers Aistech. GomSpace agreed to supply up to 100 CubeSats for their constellation worth up to EUR 12.5M [101].

Thanks to the Singapore office, GomSpace signed an 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 for their CubeSats constellation. It helped to expand the constellation to 8 Nanosats, to accelerate the company's development and to reduce GomSpace ownership share to 39% [103].

At the beginning of 2018, the Group launched a constellation of two 6U CubeSats, the GOMX-4. The project included the Technical University of Denmark, the Danish Defence, and the ESA, and wanted to demonstrate satellite communication between CubeSats using Inter-Satellite Link (ISL). These two satellites share operational components and the primary ISL payload but differ in their secondary payloads. The GOMX-4A incorporates ADS-B, AIS, and imagery payloads, while the GOMX-4B equips a propulsion module, a Chimera board, a Hyperspectral camera, and a star tracker [36].

Other IOD projects started in 2018, showing favorable company and sector development. GomSpace signed a EUR 1.575M contract with ESA to develop the Mega-Constellations Operations Platform (MCOP) at the Luxembourg office, offering Smallsats-constellation operations services. The close partner Aistech entered a contract to acquire six CubeSat platforms for EUR 1.4M under their framework agreement. Kleos Space contracted GomSpace to provide a CubeSat constellation for EUR 4.42M. Finally, A&M inked an MoU to develop a satellite constellation and ground network worth USD 100M [107].

GomSpace revised its long-term targets in 2018, aiming to have sales over SEK 1.5B in 2023 and gross margin above 50% in the medium term. The developing market in which GomSpace operates drives it to continue prioritizing growth. Thus, shareholders should not expect dividends from the short to medium term.

Two new shares issues captured financial capital during the year. In March, an accelerated book-building procedure helped to finance the sped up expansion. The issue provided SEK 125M from institutional investors. By the end of 2018, GomSpace subscribed to a preferential rights issue for by 84.5%, receiving about SEK 251M in proceeds amounting before transaction costs. It almost doubled the company's capital and the shares to SEK 3.66M and 52.27 M [107].

GomSpace experienced a notable downturn in 2018 when 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 first satellites Batch (SEK 12.766M). The project scaled down to minimums, and later GomSpace put it on hold. It led to overcapacity and, therefore, re-direction of resources to other projects and non-revenue activities, and reductions of staff. After the dismissals, the number of employees reached 231, still 32 more than a year before [107].

2019 started with a new payment plan for Sky and Space Global after the analysis of their cash flow situation. They could solve their economic situation, and a SEK 20.55M payment would arrive by March 2019. During Q1 2019, GomSpace signed a contract with the ESA to join the Nanosatellite HERA mission, and an MoU with 2Operate to boost constellation management with AI. The former will see GomSpace develop a 6U CubeSat (Juventas) for scientific tasks and landing on the Didymoon asteroid. It will be the first deep-space CubeSat developed by GomSpace. The MoU with 2Operate seeks to test terrestrial telecom standards and existing AI solutions for future satellite constellations robustly and efficiently [111].

During Q2 2019, GomSpace updated its relationship with Sky and Space Global. A Heads of Agreement would set a new deal to revise and eventually replace the original Pearls contract from 2017. In a second agreement, GomSpace would deliver 6U CubeSats, starting with a EUR 5.3M batch order of eight satellites by Q1 2020. An optional eight-satellites batch order could be delivered during H1 2020 for a cost of EUR 3.8M.

GomSpace partnered in 2019 with TESAT and KSAT to develop full optical communications capabilities in Smallsat missions and space-based services. Additionally, the firm signed two crucial contracts with ESA to adapt and improve Smallsat subsystems in deep-space science missions, valued in EUR 3.9M over 18 months, and to design the Phase A of the Miniaturized Asteroid Remote Geophysical Observer (M-ARGO) mission, similar to the HERA. The latter aims to develop a CubeSat that would rendezvous with an asteroid and perform proximity operations to identify in-situ resources. GomSpace will be in charge of the mission preliminary design, the 12U CubeSat design, and the implementation planning [111].

5.2 Business Statement and Philosophy

The mission of GomSpace is to "*help teams across the globe achieve their goals in space.*" The company aims in its 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*" [107].

Figure 5.1 shows the company's three key growth phases to follow. In the Current phase, the company is building up through investments in product development and facilities. The IOD phase requires a high degree of non-recurring engineering. Finally, in the Constellation phase, the IOD projects materialize with high volume production, leading to new projects. Nowadays, GomSpace is transitioning from the Current to the IOD phases, still focusing its investments on the products and facilities development, but already working on four IOD projects and bidding on another ten. These two phases form the basis of the company's long-term goal of sales above SEK 1.5B and the medium-term target of a gross margin of over 50% [107].

GomSpace portfolio offers two types of products; components and subsystems, to other satellite manufacturers or operators, and satellite solutions, in fully integrated satellite platforms.

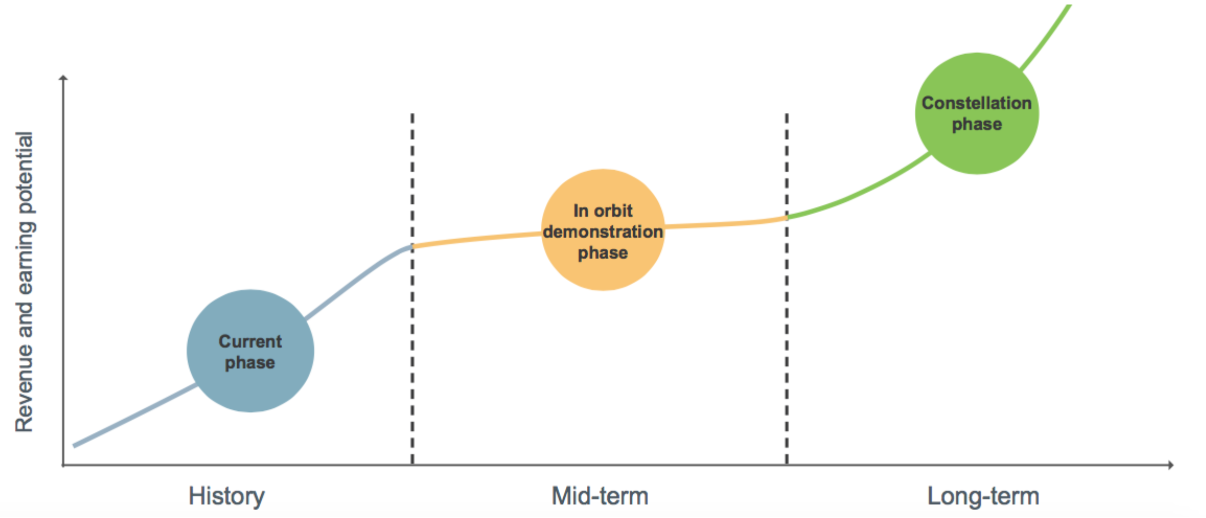


Figure 5.1: GomSpace key growth phases and revenue potential. *Image Credit: GomSpace Group AB [107].*

The services and engineering involved in these projects also produce revenues, but some are not yet available. GomSpace classifies them in its business model as constellation management services and additional services. The firm can achieve profitability over time from its engineering effort by re-using it in similar projects. Nonetheless, the trend GomSpace is showing indicates that the firm is not interested in becoming a large-scale component supplier to competing satellite manufacturers but aims to be a full-service provider. That would include satellites, constellation management, and adjacent and launching services. The company's sales of 2017 and 2018 support this trend. The first year showed that they were 65% of complete satellites and 35% of components. In 2018 the percentages varied to almost 80% and 20% [205, 107].

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*" [205]. Its competitors have used less risky strategies growing with profitability, but their chances of keeping the pace of the rapidly growing market are much lower. GomSpace has secured a high market share announcing 32% of planned CubeSats launches in 2019 and 42% in 2020. Thus, the strategy seems to be reliable [205].

The company's ambitious growth led to a parallel strategy to enter different markets. Based on the potential areas of applications that 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. GomSpace targets to increase its product demand from the new areas of application. The firm has significant added value in its current joint-venture with Aerial & Maritime Ltd and its ADS-B monitoring system constellation for aircraft tracking. Other potential joint-venture partners could be found in the Singapore Technologies Electronics, even though their relationship is so far of a supplier [205]. Nevertheless, GomSpace success stands on strengths, focus, and market fundamentals [105].

- They focused on radio-technology related missions, scalable to satellite constellations.
- They sealed significant contracts with leading constellation customers like Sky and Space Global, Aistech, Kleos, or A&M.

- GomSpace investments increased activities in growth markets like the US and Singapore. Their market shares represent 52% and 15% of the Nanosatellite market.
- They continuously invest in new technologies, through IOD and new applications, and in new machinery for product industrialization.
- They built the Luxembourg-based service for operations and constellation management.
- The positive outlook the space industry shows to Nanosatellite manufacturers who respond with improved performance benefited GomSpace.
- The firm profits from a rapidly growing market with continuous increases in launches.

5.3 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. The GomSpace Group structure can be observed in Figure 5.2, while the subsidiaries are listed below [107].

GomSpace A/S: It is the core subsidiary of the Group, and its location is at the company headquarters in Denmark. It deals with the design, integration, and manufacturing of the high-end CubeSats parts and complete solutions. The launch services facilitator subsidiary, GomSpace Orbital ApS, is a part of it.

GomSpace Sweden AB: Formerly known as NanoSpace AB, this Swedish subsidiary develops and provides propulsion technology products for Nanosats. It hosts a propulsion technology center in Uppsala.

GomSpace ASIA Pte Ltd: Located in Singapore, this sales & project development office spearheads the company's growing operations in Singapore and Asia.

GomSpace North America LLC: WWith its office in Washington, DC, this sales & project development office plays a significant role in the attention-catching of the US and American continent markets.

GomSpace Luxembourg SARL: Being located in Luxembourg, this subsidiary aims to develop an operations center as a service for Nanosats constellation management.

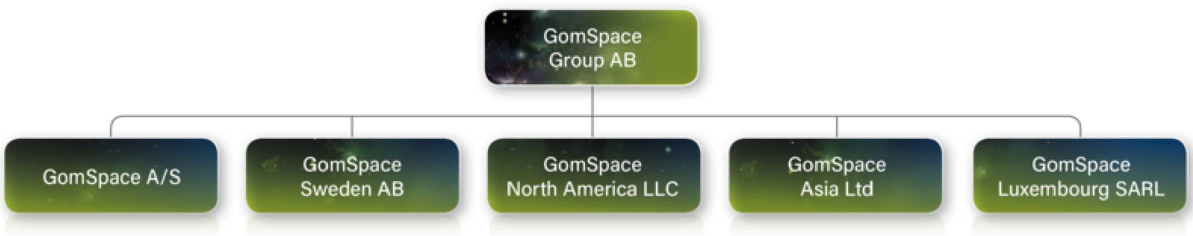


Figure 5.2: GomSpace Group structure. *Image Credit: GomSpace Group AB [107].*

5.3.1 Ownership

GomSpace Group AB is own by different shareholders. With the last preferential rights issue nearly doubling the number of shares on March 31, 2019, the company had 52,274,803 outstanding shares. The annual general meeting on April 26, 2019, augmented the lower and upper limits of the number of the shares to 50 M and 200 M. Similarly, the share capital thresholds increased to SEK 3.5M and SEK 14M [69]. These shares can be distributed in four owner groups shown in Table 5.1.

Table 5.1: GomSpace Group AB shares distribution [169].

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 issue of shares. The Board of Directors and the Management hold 5,338,646 and 1,562,132 shares respectively, representing 13.2% of the company's shares. Table 5.2 exhibits the principal public shareholders, representing 30.6% of the shares. All the company shares are equal; hence each share entitles to one vote at shareholder's meetings [169, 206, 107].

Table 5.2: GomSpace Group AB main public shareholders [206].

Shareholder's name	Percent of share capital and votes
JML Invest ApS	12.5%
Hansen & Langeland ApS	10%
MediumInvest A/S	5%
Borean Innovation A/S	3.1%

5.3.2 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 vital decisions, oversee performance, and choose CEOs. The Board of Directors at GomSpace must be more than three members, but not over seven [104].

Jukka Pertola - Chairman: Mr. Pertola has been a Board member and its Chairman since 2016. He has over 20 years of experience in management fields, in addition to 10 years as a Board member. Born in 1960, he holds an MSc in Electrical Engineering from the Helsinki University of Technology. He holds directly 40,000 shares of GomSpace [104, 107].

Jesper Jespersen - Vice Chairman: Mr. Jespersen is also a Board member at several companies within the NOVI/BOREAN group, with 18 years of CEO experience. Born in 1946, he obtained an MBA from the Aarhus Business School and a Mini MBA from Stanford University. He holds directly 50,000 shares of GomSpace [104, 107].

Steen Lorenz Johan Hansen - Board member: Mr. Hansen, born in 1948, has 39 years of experience as CEO. He holds an MSc in Electrical Engineering from the TU 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%) [104, 107].

Hans Henrik Schibler - Board member: Mr. Mr. Schibler is a Board member since spring 2019. He has ten years of experience as Chief Financial Officer (CFO) in large-scale businesses. Born in 1978, he holds a Master's in Economics and an MBA from the Copenhagen Business School. He does not own any GomSpace share [104].

5.3.3 Executive Management

The Executive Management is lead by the CEO and heads the organization towards the Board directions. They make operational decisions and policies, and keep the board informed and educated through well-documented suggestions and information. They are 5 key members.

Niels Buus - CEO: Mr. Buus has been GomSpace CEO since 2014. He has over 20 years of experience in the defense and security business. Born in 1957, Mr. Buus holds an MSc in Leadership and Strategy from the London Business School, an MSc in Applied Optics from the Imperial College, and an MSc in Optics Mechanical Eng. from the Aalborg U. He holds directly 38,000 company shares as well as indirectly 1,221,759 through Longbus Holding ApS. His wife holds directly 2,000 [107, 205].

Troels Dalsgaard Nørmølle - CFO: Mr. Nørmølle has been GomSpace's CFO since 2014. Born in 1986, he has over ten years of experience in accounting and holds a Graduate Certificate in Business Administration from the Aalborg U. He directly holds 1,000 shares while indirectly holding 293,300 shares through Skallerup Invest IVS. His children hold 3,000 directly [107, 205].

Dan Ulrich - Chief Compliance Officer (CCO): Mr. Ulrich used to be the CTO until December 2018, when he took his current position. He has over twenty years of experience with complex technology, new business, and airspace and defense development. Born in 1962, Mr. Ulrich has an MSc in Chemistry, an Industrial PhD from the TU of Denmark, and an executive MBA from the Ashridge Management College. He holds directly 3,076 GomSpace shares [107, 205].

Morten Hvidberg Jeppesen - CTO: Mr. Jeppesen started as CTO in December 2018. Born in 1975, he has experience worldwide in engineering companies and holds an MSc in Digital Signal Processing from the Aalborg U. He holds directly 4,655 shares [107].

Peter Høy - Chief Procurement Officer (CPO): Mr. Høy is a CTO since August 2018. One year earlier, he joined GomSpace as Production Director. Born in 1957, he holds an MSc in Economics, an MBA from the Aarhus School of Business, and has vast experience in executive management positions. He holds directly 3,370 GomSpace shares [107].

5.3.4 Employees

GomSpace Group AB had 134 employees on December 31, 2019. The company classifies them by their field of expertise in technology, manufacturing, sales and distribution, or administration.

They are 82, 30, 11, and 11, respectively. Since the end of 2018, the number of employees has decreased by 97 due to overcapacity, mostly within manufacturing (39) and technology (29). It is related to the payment delays from Sky and Space Global and the cease of this project activities. Table 5.3 presents the offices' distribution of employees at the end of 2018 and 2019 [112, 111].

Table 5.3: GomSpace Group subsidiary employees distribution ending 2018 and 2019 [112].

Subsidiary name (Country)	**Number of employees (% of women)**	
	2018	**2019**
GomSpace Group AB (Sweden - Parent Company)	2 (50%)	1 (100%)
GomSpace A/S (Denmark)	200 (24%)	100 (18%)
GomSpace Sweden AB (Sweden)	20 (10%)	18 (6%)
GomSpace Luxembourg S.A.R.L. (Luxembourg)	7 (14%)	14 (7%)
GomSpace ASIA Pte Ltd (Singapore)	1 (0%)	0 (0%)
GomSpace North America LLC (USA)	1 (0%)	1 (0%)
Total	231 (23%)	134 (16%)

GomSpace's web page defines its working culture as informal and transparent in communication. The organization is supposedly built upon multidisciplinary skills and engineering passion. They state that the company is about people, as "*Treasuring our Employees is Essential to Treasuring our Customers*" [66]. Thus, five values are defined to serve as guidance to back the company key behaviors. 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 that bring valuable differences.

GomSpace seeks employees that would live their values with integrity and passion, committing to excellence and open communication in any job situation. Cooperation and collaboration between talented people are essential aspects of the company. They help to achieve the firm's full potential. [66].

The GomSpace web page presents the experiences of six employees. They positively highlight the informal working environment, the company values, GomSpace's perspective of growth, and its sector leadership. Technical employees showed excitement over project developments using innovative technologies, and the satisfaction when their creations are orbiting. GomSpace social events and flexible working times contribute to less-stressful jobs and effective results [65]. These descriptions only collect positive aspects of working at GomSpace. A sole external review was found from a systems engineer that summed up his job interview. He stated in 2016 that the recruitment process took about a week, he video-chatted with the CEO and CTO, and got hired. His experience was neutral, but they were reasonable with his compensation requests [51].

5.4 EO Market Segment and Requirements

GomSpace's business model, business segments, and solutions divide this section.

5.4.1 Business Model

The firm bases its competences in the radio technology. Its size and capabilities are especially interesting for Nanosatellites. The company revenues come from five sources, as the business model in Figure 5.3 shows. They are the subsystems, complete platforms, payloads, constellation management, and additional services, which will be explained in further sections [105].

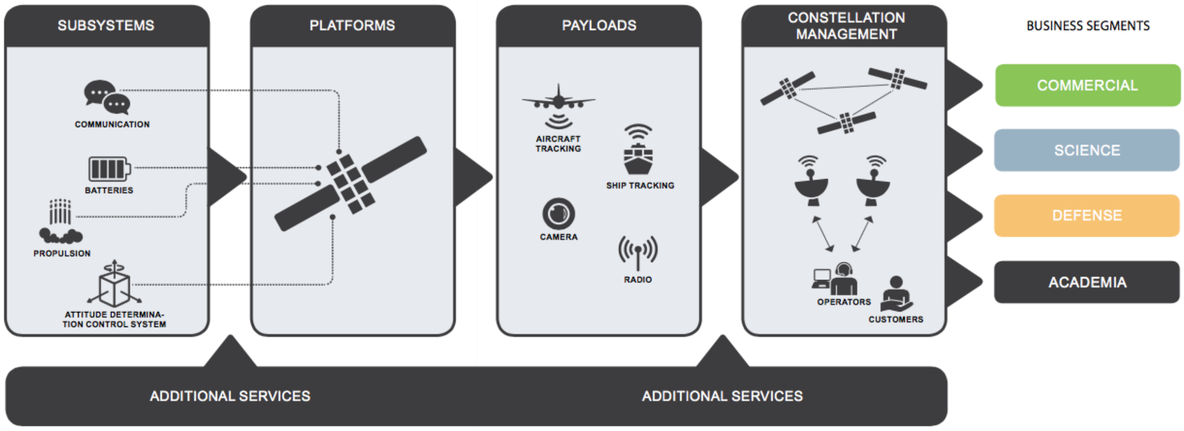


Figure 5.3: GomSpace Group AB business model. *Image Credit: GomSpace Group AB [107].*

The company's profitability relies on re-using engineering time in similar projects. The components modularization and versatility make them adaptable to CubeSats for various purposes. GomSpace supplies components and complete projects, but it aims to become a full-service provider. The firm is becoming reluctant to supply components to competing satellite manufacturers, while its launch and constellation management services keep building up [205]. Figure 5.3 also presents the four business segments in which GomSpace operates.

5.4.2 Business Segments

GomSpace focuses its sales in four different business segments; Academia, Commercial, Defense, and Science. Revenues are divided by these segments for 2017, 2018, and 2019 in Table 5.4. The most significant segment is the Commercial, thanks to the Sky and Space Global, Aistech and Kleos major contracts. The Science segment has gained importance over time, becoming the second-largest and diminishing the Academic. The Defense segment has marginal revenue percentages. However, the commercial segment has lost relevance in 2019 due to the difficulties with Sky and Space Global [107, 112].

GomSpace business segments have different importance around the world. Table 5.5 presents the percentage of 2019 revenues obtained in GomSpace's six geographical regions and its overall share in the company's sales. The total revenue for 2019 was of SEK 136,263k [112]. The firm also divides its main offerings between satellite solutions, platforms, payloads and subsystems, product sales, and management fees. The satellite solutions refer to entire CubeSats platforms

Table 5.4: GomSpace Group AB business segments revenues distribution [107, 112, 111].

Segment	2017	2018	2019
Commercial	74.63%	78.72%	53.43%
Science	8.33%	10.61%	35.25%
Academic	13.31%	7.02%	8.53%
Defense	3.72%	3.65%	2.80%

while the other items of the group gathers the subsystems and payloads sold separately. During 2019, 72.53% of revenues came from satellite solutions, while in 2018 the share was 77.09%. It decreased slightly but in general it is maintained [111].

Table 5.5: The Group 2019 revenues by business segment and geographical region [112].

Region	Academia	Commercial	Defense	Science	Total
Sweden	0.15%	1.32%	0%	0.96%	**2.43%**
Denmark	0.96%	2.14%	0%	0%	**3.10%**
Rest of Europe	2.08%	41.82%	0.43%	29.44%	**73.77%**
USA	1.48%	3.93%	1.48%	0.19%	**7.08%**
Asia	1.66%	3.21%	0%	4.38%	**9.25%**
Rest of the World	2.19%	1.00%	0.89%	0.30%	**4.38%**
Overall	8.53%	53.43%	2.80%	35.25%	**100%**

5.4.3 Solutions

The Group offers solutions in six unique areas with its products. CubeSats should provide revenue or mission-critical services to their owners.GomSpace facilitates the projects required to achieve it. Those projects are turnkey and fully transparent to the customer, using recognized standards. The firm claims to have a flexible portfolio, benefiting from radio payloads building blocks, continuously innovated applications, and in-orbit second-to-none performance [75].

5.4.3.1 Global Tracking

Global asset tracking using satellites is being widely generalized. The broadcasted information is standardized and gains relevance with time. GomSpace has powerful experience with vessel and aircraft tracking through receiving AIS and ADS-B signals. They have improved these technologies through their GOMX-1 and GOMX-3 missions. Thus, the firm can develop entire on-demand Nanosatellite constellations for tracking based on high coverage and revisit times. The Group can design other tracking solutions using its radio technology building blocks. Companies like A&M or Aistech already benefit from this solution [108].

5.4.3.2 Internet of Things (IoT)

Full two-way communications between devices are essential nowadays. GomSpace provides it through satellite-based IoT, allowing remote management of assets, herd tracking, fleet management, or smart metering. The Group backs the IoT technology on RF and signal processing experience. That includes low-power front-end electronics, SDR, signals from VHF to Ka-band, complex signal processing, and antennas from monopoles to patch arrays. The firm also assists with the corresponding IoT ground terminals [110].

5.4.3.3 Communications

The company provides more generalized communications solutions. Backed by their RF and signal processing experience, they developed the bespoke communications system. It includes advanced features such as ISL capabilities, satellite power generation, and distribution. This technology was tested onboard the GOMX-3 mission and supports demanding radio payloads and station keeping capabilities. Sky and Space Global benefits from it [59].

5.4.3.4 Remote Sensing

GomSpace views EO Nanosatellites as a cost-efficient entry-level platform before going to higher resolutions. These constellations can provide medium resolutions with high temporal update rates. GomSpace offers different EO payloads such as IR, hyperspectral, and optical sensors. The GOMX-4 mission aims to demonstrate new hyperspectral imaging systems [72].

5.4.3.5 Defense and Security

Military, intelligence, and security solutions have special requirements that GomSpace can meet. Tested and well-proven platforms may include the previous four solutions, but unique defense projects also need skillful handling. For instance, they need discretion, secure data encryption, and other cyber-security measures. New space-based capabilities integrated into C4ISR infrastructures and additional Electronic counter-countermeasures resilience are required. The Group has vast experience in this field, taking part in projects like the Ulloriaq Arctic Surveillance/GOMX-4 with the Danish Defense, or the HawkEye360 [63].

5.4.3.6 Science Missions

Science missions to understand the universe and beyond get benefits from cost-efficient Nanosats. They can be used as a first space approach before big-ticket missions. The company offers science customers a flexible product portfolio, resulting in effective mission platforms. They include formation flying, rendezvous, docking, and mature propulsion technology, ideal for deep-space attitude control. GomSpace has experience in space missions, understanding, and supporting them with low costs and risks [73].

5.5 Satellite Payloads and Subsystems

GomSpace Group bases its production of satellites in CubeSats. Each CubeSat contains several subsystems that perform the necessary functions to operate in space. The regulated 1U unit cubes locate the subsystems and allow GomSpace to standardize them. Thus, the Group produces a large number of subsystems with top quality, low lead time, and attractive costs. Similarly, a payload is a subsystem that executes a satellite mission task. 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 [111, 105].

GomSpace has developed, qualified, and in-orbit validated payloads and subsystems through the GOMX flight test program. Its worldwide customers operate in many business segments, backing the firm products. The COTS nature of these standard components makes them reliable, plug-and-play solutions, allowing companies to focus on their mission objectives [68].

5.5.1 Mission Payloads

The strength of GomSpace payloads relies on their state-of-the-art radio technology such as advanced tailored radio solutions, advanced signal processing from SDR, and all types of antennas from 0 GHz to 40 GHz. Payload solutions are specified, designed, and software-enabled to meet all requirements. The firm classifies its payloads in Aircraft Tracking ADS-B, Ship Tracking AIS, SDR, and Optical EO [111, 105].

5.5.1.1 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. This transceiver gets the ADS-B signal transmitted by an aircraft at 1,090 MHz with its ID, position, and status. The GOMX programs have developed and tested in-space this system.

The **NanoCom ADS-B** contains an RF front-end transceiver, an in-orbit reconfigurable Field-Programmable Gate Array (FPGA), and a Micro-controller unit. Its transceiver amplifies and down-converts the signal, which later the FPGA samples and runs on it the decoding algorithms. The last element stores the data and delivers it to the CSP network if there is an opportunity for downlink. This payload only requires 0.3U CubeSat units and consumes 0.5 W of power. The maximum data packages per second it can receive is about 800 [85, 13].

The **NanoCom ANT1090-P patch antenna** connects to a GomSpace SDR transceiver. It is available in passive or active versions. Its flexible sandwich construction allows one to mount it in many structures, while its integrated composition with low-noise amplifiers and filters results in low losses and optimum RF noise figure performance. Its gain is 4.5 dB [86].

5.5.1.2 Ship Tracking AIS

The **Satlab QubeAIS Software-Defined AIS Receiver** is a self-contained SDR intended for space-based ship tracking. It weighs under 55 g, consumes 0.8 W at full load, and has a sensitivity of −113 dB. It is software reconfigurable for AIS at 162 MHz and long range at 156.8 MHz. The QubeAIS can download raw RF spectrum samples and has low-noise amplifiers, RF filters, and data storage. It comes with an easy-integration software library and operates with a passive antenna connected through MCX or SMA [166].

5.5.1.3 Software Defined Radio (SDR)

The NanoCom SDR is a platform with sensing and communication capabilities that uses advanced FPGA technology. It carries a NanoDock SDR motherboard, a NanoMind Z7000

On-Board Computer (OBC) and FPGA, and a NanoCom TR-600 transceiver. This modular CPU, FPGA, and radio for Smallsats can be in-orbit reprogrammed, weighs 300 g, and adapts to many configurations with high versatility and low volume. The modularized architecture, known as the GomSpace Mother/Daughterboard concept, allows one FPGA and up to three transceiver modules. The FPGA can execute advanced signal processing and detection techniques, while the transceiver modules perform S-band ground link and S-/K-band ISL [88].

5.5.1.4 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 hosted in a standard 1U CubeSat structure. Three different lenses are available; 8 mm, 35 mm or 70 mm, ordered in increasing resolution. The payload weighs 170 g with the first two lenses and 280 g with the third. This 3-megapixel color sensor is capable of advanced data processing and storage using its 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 [79].

5.5.2 Power Systems

GomSpace product line covers all the parts of a satellite power system; the solar panels, the power supplies, and the batteries. They provide the power to the satellite, control it, and store the unused generated power, respectively [111].

5.5.2.1 Power supplies

The Group offers two power supply models; the NanoPower P31u and the NanoPower P60. The first is suitable for platforms smaller than a 3U CubeSats, while the second power supply is recommended for bigger Nanosats. Both have been extensively in-orbit tested 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 battery. It delivers up to 30 W and uses a strictly KISS design philosophy. The incorporated lithium-ion battery pack has 20 W h at 8 V [96].

NanoPower P60: It is a modular EPS with a P60 Dock motherboard that hosts an Array Conditioning Unit and up to four Power Distribution Units. It has synchronized out-of-phase converters for low electromagnetic interference operations. The battery voltage can be 16 V or 32 V [106].

5.5.2.2 Battery Packs

The GomSpace battery packs are composed of COTS lithium-ion cells proven in space. The firm offers two packs; the NanoPower BP4, a standard four cells module, and the NanoPower BPX, a high-capacity eight cells pack with an autonomous heater system.

NanoPower BP4: This pack weighs about 270 g and has 38.5 W h. Its two variants deliver 2,600 mA h at 14.8 V, or 5,200 mA h at 7.4 V. GomSpace recommends pairing the NanoPower BP4 with the NanoPower P31u for longer CubeSat life [81].

NanoPower BPX: It is a customizable battery pack with a capacity of 77 W h. Its three available configurations have a nominal voltage of 7.4 V at 10,400 mA h, 14.8 V at 5,200 mA h, and 29.6 V at 2,600 mA h. The system is expandable by connecting packs in parallel or serial [82].

5.5.2.3 Solar Panels

GomSpace mounts its solar panels on aluminum plates outside the satellites. They are based on 30% efficient ITAR free cells, with each one producing 1.15 W at LEO. They assemble the cells in a space-qualified triple junction and integrate magneto-torquers, coarse sun-sensors, and temperature sensors. The company offers three CubeSat solutions, the NanoPower MSP, the NanoPower DSP, and the NanoPower P110.

NanoPower MSP: It is a modular system with the cell plates shielding 6U or 12U CubeSats. Many cell setups are possible for each satellite face, covering all its surfaces besides the antennas and sensors to provide optimum energy production [95].

NanoPower DSP: Three panels connected with spring-loaded hinges compose this system. One panel covers the 3U or 6U CubeSat while the other two, folded at launch, deploy when orbiting. Two versions are available, with 135° and with 90°. The satellite-attached panel of the latter does not have solar cells, while the former has [91].

NanoPower P110: It is an integrated side panel with two solar cells that cover a 1U side of 1U and 2U CubeSats [89].

5.5.2.4 Power Packs

Regarding the needs of GomSpace customers, the company has tailored solutions for 1U, 2U, and 3U CubeSats. These **NanoPower systems** are full power solutions that include maximum power point tracking, charging management, controlled power distribution, and single-board batteries in compact space. The 1U PowerPack includes one NanoPower P31u power supply with battery and six NanoPower P110 solar panels. The 2U PowerPack is similar to the previous but has ten NanoPower P110 solar panels. Finally, the 3U PowerPack combines a NanoPower P31u power supply, a NanoPower BP4 battery pack, and fourteen NanoPower P110 solar panels. All the packs come with six coarse sun-sensors, three magnetorquers, and a harness kit [90].

5.5.3 Communication Systems

GomSpace radio communication products divide into space segment and ground segment. They can transmit and receive telemetry, satellite control, and payload data [60].

5.5.3.1 Space Segment

Communication products mounted on-board CubeSats provide ground-link and ISL communications. GomSpace offers high-speed S-band and UHF/VHF radio communication products, including transceivers and antennas [60].

NanoCom SR2000: It is a flexible, ready-to-use S-band transceiver build on an SDR platform that supports ground-link and ISL communications. Configurable from space, it uses a flexible layer bandwidth up to 1.25 Mbps. It should be used with the antenna ANT2000.

NanoCom AX100: It is a UHF/VHF communication miniaturized transceiver whose modularity allows redundancy and flexible link frequency. Its data rates go from 0.1 kbps to 115.2 kbps and should team up with the NanoCom antennas ANT-6F or ANT430.

NanoCom TR-600: It is a customizable RF front-end transceiver used with an SDR platform. In-orbit reconfigurable, it incorporates an AD9361 transceiver, a tunable channel bandwidth from 200 kHz to 56 MHz, and EEprom. It operates from 70 MHz to 6 GHz.

NanoCom ANT2000: It is an 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 comprises four monopole antennas with gains 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, it is suitable for 6U CubeSats with UHF and VHF.

5.5.3.2 Ground Segment

The Group ground segment products allow customers to set up a ground station and communicate with their satellites. The firm provides ground station radio units, antennas, and mission computers with software.

NanoCom GS100: It is a ground station dual-radio solution for UHF and VHF. It includes two internal NanoCom AX100 radio modules with polarization diversity and simplified hardware development.

NanoCom GS2000: It is an S-Band ground station radio transceiver mounted in a 2U rack-cabinet with a supply of 28 V. It can connect a receiving and a transmitting antenna.

NanoCom AS100: It is an UHF ground station antenna with a satellite tracking rotor. It has a 4 m high tower with two Yagi antennas, a rotor controller, and elevation and azimuth rotors. It has enough gain to perform LEO satellite communications (17 dB).

NanoCom AS2000: It is a ground station antenna with a satellite tracking rotor for LEO communications. It has a 1.2 m S-band dish antenna, two 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, used as a hub between the satellite and the user. It has a Linux operative system, an Intel Xeon E3-1220 3 GHz processor, 500 GB of storage, and 4 GB of RAM. The software incorporates a rotor controller for satellite tracking and radio Doppler compensation.

NanoCom GND UHF/VHF: It is GomSpace's complete UHF/VHF ground station, including a NanoCom AS100 antenna tower, a NanoCom GS100 transceiver, and a NanoCom MS100 computer. The ground station can be controlled via Ethernet or Internet.

5.5.4 Command and Data Handling

GomSpace offers powerful and miniaturized OBCs to control satellite operations and payloads. It comes with the required software to execute any mission, which has a network vision where subsystems are autonomous nodes. They communicate freely to each other, but the ground station can control them. The CubeSat Space Protocol (CSP) physical networks and the router-like role of the transceivers are essential. The hardware platform supports this distributed architecture, achieving a small, low-risk, and fully integrated satellite [58].

5.5.4.1 NanoMind A3200

This highly miniaturized OBC involves an 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, while the rest are used for attitude control. The OBC incorporates a high-performance AVR32 MCU with advanced power-saving features, a 512 kB build-in flash, a 128 MB NOR flash for storage, and 32 kB of FRAM for persistent configuration storage. Its 0.17 W consumption makes the NanoMind A3200 ideal for CubeSats, Nanosats, and Microsats [80].

5.5.4.2 NanoMind Z7000

This powerful ARM and FPGA OBC is GomSpace's solution for demanding CubeSat applications like 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 and 32 GB of storage. The NanoMind Z7000 has a Linux operative system, and its thermal load is controlled by a precision-milled anodized heat sink that provides electromagnetic shielding. Its power system gets dually divided between the ARM and the FPGA. Its maximum power consumption is 2.3 W [99].

5.5.4.3 Platform Software

The Group offers software forOBCs and ground stations that 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 the NanoMind A3200 and Z7000 OBC and the NanoCom MS100 computer. The software uses CSP communication with the drivers, allowing the user to change parameters and get OBC data.

The SDK software includes a set of advanced and feature-rich 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 historical and real-time satellite telemetry data. It is highly customizable, can integrate various libraries, and incorporates a few sub-pages that display pre-set modules. Due to its browser-based nature, multiple users can review real-time data simultaneously [74, 49].

5.5.5 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.

5.5.5.1 ADCS System

The ADCS system's objective is to control the satellite navigation regarding the angle to the sun, the distances to the Earth and other satellites, or to meet the critical mission requirements. It usually comprises some subsystems hosted in a single ADCS box, but it is often better to have them apart in Nanosats. The modularization of GomSpace CubeSats facilitates high-performance solutions with separated subsystems [62].

Magnetorquer: GomSpace offers two magnetorquers; the **NanoTorque GST-600** and the **NanoTorque Z-axis Internal**. The former is a 3-axis device designed for 6U CubeSats or larger, and the latter is a single-axis system for smaller Nanosats. While a single air-torquer and two magnetorquer-rods compose the GST-600, the Z-axis Internal only has an air-torquer. Their axis torque moments are over 300 m A m and 139 m A m [83, 78].

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 [94].

GPS receiver: The **NanoSense GPS kit** includes a customized dual-frequency NovAtel OEM-719 GPS receiver module and an antenna. It has no COCOM limitations, requires 3.3 V, and its position and velocity precision are 1.5 m and 0.03 m/s, respectively [93].

Reaction Wheel: The Group's 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 four-wheels redundant structure as a pyramid or as a 3 + 1 without mounting bracket. It is designed for long life, with hybrid bearings, a brushless motor, a balanced flywheel, integrated electronics, lubricant-free, and an enclosed design [84].

Fine Sun-Sensors: The **NanoSense FSS** is the firm's high-precision and ultra-compact device that comes with a digital interface (I2C), a wide field-of-view, and an elevator unit. It is flexibly mounted, consumes low power, and weighs 2.2 g [92].

ADCS Software: The company's **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 sensors, actuators, and propulsion systems, to perform advanced positioning, attitude determination, and control [57].

5.5.5.2 Propulsion Systems

GomSpace offers cold-gas propulsion systems compatible with their ADCS system. They offer two different solutions; for 6U CubeSats and larger, or 2U and 3U. It ejects the butane gas through four thrusters to control the satellite in any direction. The gas consumption is very low, with delta-V from 8 m/s to 13 m/s, ensuring a mission lifetime operative duration.

NanoProp CGP3 3U Propulsion: It is a MEMS propulsion module for 2U and 3U CubeSats. The module holds a butane tank, four individually controllable thrusters, closed-loop thrust control, and integrated flow sensors that provide real-time thrust measurements. It has a trust of 1 mN, a total impulse of 40 N s, a wet mass of 350 g, and only requires about 0.5U of CubeSat volume [97].

NanoProp 6U Propulsion: It is a MEMS cold-gas propulsion module for 6U CubeSats and beyond. It is a developed version of the NanoProp CGP3, incorporating two butane tanks, a trust of 10 mN, a total impulse of 80 N s, a wet mass of 900 g, and taking 2U wide and 0.5U high [98].

5.6 Platforms and Services

The company offers products in the five groups of its business model; subsystems, payloads, complete platforms, constellation management, and additional services. They are the company's sources of revenue. This chapter will approach the three last groups [105].

5.6.1 Satellite Platforms

For over ten years, GomSpace has been involved in the NewSpace sector. The Group configures its broad subsystems portfolio in many platforms to fulfill the client's mission requirements. The company states that its strengths rely on its product flexibility, and the GOMX program results in development, qualification, and validation.

The Group offers proven 1U, 2U, 3U, and 6U CubeSat platforms, which undergo its program for testing and validation in thermal cycling and stress, vibration, radiation, and heated vacuum. GomSpace delivers its platform with standard subsystems and ready to integrate an external payload in four to six months after the order reception.

The Q1 2019 Interim report from GomSpace Group AB [111] mentions that the new 8U platform is already being offered, even though it is not available on its web page. The company is investing many resources to develop in new 12U and 16U CubeSats as the market demands evolve. An example of the 12U is the M-ARGO mission [71].

5.6.1.1 1U and 2U CubeSat Platforms

The smallest available CubeSats in GomSpoace are ideal for simple in-space experiments involving radio communications, EO, and academic programs. They are also desirable for Nanosatellite integration and in-space operation training. The Group only describes the 1U platform, considering the 2U as an expansion of the previous.

Power System: It comprises the 1U PowerPack with a NanoPower P31u and six NanoPower P110 solar panels.

Mechanics: It is the 1U CubeSat structure with full Harness Set.

Command and Management System: It is the OBC NanoMind A3200 with the software for satellite control, and the mission library for flight planning and data collection.

Communications System: It involves the UHF NanoCom AX100 transceiver, the NanoCom ANT430 antenna, and the NanoMind A3200 OBC.

ADCS System: It incorporates the ADCS software and integrated magnetorquers NanoTorque GST-600 for essential stabilization and satellite alignment.

The firm upgrades the platform with a NanoCam C1U camera. GomSpace is developing the 1U subsystems since 2014, and Table 5.6 shows its technical information [54].

5.6.1.2 3U CubeSat Platform

GomSpace bases its 3U standard platform on the successful IOD GOMX-3 mission. The firm states that this platform is useful to perform air traffic data collection through ADS-B, vessels monitoring through 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.

Power System: It comprises the 3U Power Pack with a NanoPower P31u, the NanoPower BP4 battery pack, and fourteen NanoPower P110 solar panels.

Mechanics: It is described as the 3U CubeSat structure with full Harness Set.

Command and Management System: It is the OBC NanoMind A3200 with the software for satellite control, and the mission library for flight planning and data collection.

Communications System: It involves the UHF NanoCom AX100 transceiver, the NanoCom ANT430 antenna, and the NanoMind A3200 OBC.

ADCS System: It incorporates the ADCS software for fine stabilization, a NanoMind A3200 ADCS, a NanoSense GPS kit, one reaction wheel for 1-axis control, six NanoSense FSS, and a NanoSense M315 magnetometer.

Upgrades to the standard configuration can be included with extra battery packs, deployable solar panels, fast data downlinks, on-board propulsion system, and a more precise ADCS system [55]. Table 5.7 shows the 3U CubeSat technical information.

5.6.1.3 6U CubeSat Platform

The Group bases its 6U standard platform on the IOD GOMX-4 mission. Similarly to the 3U CubeSat, this platform is useful to perform air traffic data collection through ADS-B, vessel monitoring through AIS, professional radio and IoT data communications, IOD, and science missions. Besides, the 6U platform is ideal for forming satellite constellations.

Power System: It comprises a NanoPower P60 EPS, a NanoPower BPX battery pack, and NanoPower MSP solar panels as customized.

Mechanics: It is the 6U structure with full Harness Set and internal mounting rings.

Command and Management System: It is the OBC NanoMind A3200 with the software for satellite control, and the mission library for flight planning and data collection.

Table 5.6: GomSpace 1U CubeSat technical information. *Adapted from GomSpace [54].*

Platform		Payload	
Size	1U	**Payload space**	0.3U
Peak Power	3.4 W	**Av. Payload Power**	Depending on orbit
Battery Capacity	20 W h	**Max. Payload Mass**	1 kg
Platform Mass	0.95 kg	**Payload Interfaces**	CAN bus
Platform lifetime	< 1 year	**Power Bus**	3.3 V or 5 V

Table 5.7: GomSpace 3U CubeSat technical information. *Adapted from GomSpace [55].*

Platform		Payload	
Size	3U	**Payload space**	1.8U
Peak Power	8 W	**Av. Payload Power**	Depending on orbit
Battery Capacity	38 W h	**Max. Payload Mass**	1.8 kg
Platform Mass	2 kg	**Payload Interfaces**	I2C, UART and CAN bus
Platform lifetime	< 5 years	**Power Bus**	3.3 V or 5 V

Communications System: It involves the UHF NanoCom AX100 transceiver, the NanoCom ANT430 antenna, and the NanoMind A3200 OBC.

ADCS System: The ADCS software for fine stabilization, a NanoMind A3200 ADCS, a NanoSense GPS kit, four NanoTorque GSW-600, six NanoSense FSS, a NanoTorque GST-600, and a NanoSense M315.

The company can add upgrades to the standard configuration. They include improved pointing, position knowledge and control through extra ADCS system elements, a cold-gas propulsion system, or increased payload and platform power through larger deployable solar panels [56]. Table 5.8 exhibits this satellite technical information.

Table 5.8: GomSpace 6U CubeSat technical information. *Adapted from GomSpace [56].*

Platform		Payload	
Size	6U	**Payload space**	4U
Peak Power	12 W	**Av. Payload Power**	Depending on orbit
Battery Capacity	77 W h	**Max. Payload Mass**	4 kg to 6 kg
Platform Mass	5.6 kg	**Payload Interfaces**	I2C, UART and CAN bus
Platform lifetime	Designed 5 years	**Power Bus**	3.3 V, 5 V, 8 V 12 V 18 V or 24 V

5.6.2 Constellation Management

Satellite constellations have to be operated under shared control due to the complexity that large satellite numbers bring. GomSpace is developing a system for constellation management, providing in-orbit satellite operation services. They see these services with significant long-term potential as the rate for constellation services is about 20% of the satellite cost. Regarding a five-year CubeSat lifetime, the potential constellation management revenues equal the initial Nanosatellite cost [105, 205].

The product GomSpace is developing for constellation management is the Mega-Constellations Operations Platform (MCOP). It will result from a collaboration with the ESA to develop the platform at their Luxembourgian offices. The company claims that the MCOP service is designed from the ground up, being a cost-effective solution for single satellites and large constellations with optimized ground segment management. It presents a holistic approach in space and ground segments and is under continuous development. The firm divides the platform into three areas [61].

Satellite Operations: With the most modern software, automation, end-to-end integration, and scalability, the MCOP can manage constellations and optimize business-wise. The automation is essential, allowing clients to focus on value improvement of the missions and near-instantaneous change in operational modes.

Network Management: The MCOP connects the satellites, ground stations, data centers, extensive area networks, and end-user service delivery points to have them under control. Hence, network management of the MCOP requires and provides end-to-end assets monitoring, centralized configuration, redundancy management, autonomous network operations, fault recovery, and service quality management.

Mission Exploitation: The MCOP platforms can help a business to design and implement algorithms and business logic. It 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.

5.6.3 Additional Services

The additional services that GomSpace can offer to a customer are vast. They range from punctual mission services to full mission development and design [105, 205].

Payload and subsystems integration: The Group offers platform integration of in-house payloads and subsystems, payload junction development, and customer integration.

Engineering support: The company offers engineering support at any point in the mission, focusing on the Launch and Early Orbit Phase (LEOP).

Ground Station support: Besides the constellation management, the firm offers ground station support by providing elements to the station or helping in its operation.

Launch services: The Group offers launch services, especially 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.

5.7 Production System

The GomSpace headquarter is in Aalborg, Denmark, where the majority of the product development occurs. It includes the integrated satellite assembly, the integration, and the testing of payloads and subsystems. The last two are composed of different electronic boards and mechanical parts supplied by local trusted suppliers, ensuring low-cost, high-quality, and flexibility. However, the firm tests the components before their integration. The company aims to become a systems integrator, applying its means and skill set to manufacture complete satellites using payloads and subsystems build by GomSpace or other suppliers [105].

The Group enlarged its facilities to ramp-up its productions, going from low- to high-volume. According to a Danske Bank Commissioned Research, the increase in modularization and production automation, together with the facilities enlargement, augur a successful transition to the high-volume production. GomSpace expects to produce up to one CubeSat a day with serial production, applying VIS and Lean Manufacturing [205].

5.7.1 GomSpace Methods to Reduce Development Time

GomSpace understands the role that Nanosatellites have in the space sector as secondary payloads. Accelerated schedules are typical among their development. This forces Nanosat companies to center their project schedules in the subsystems development. Thus, little time is left for system-level testing or higher-level functionality. The essence of the Nanosats is to compete with traditional satellites by being faster, cheaper, and better. Up to date, the “faster" and “cheaper" factors have passed the test, but the “better" is still in jeopardy. Regarding the radiation of kW of power, the astronomical and terrestrial imaging, CubeSats are still worse than traditional satellites. Hence, the “better" factor is measured with its Return of Investment. It can have various meanings, going from faster and cheaper test cycles to a quick deploy and scale of the service. It avoids devaluation during the development phase with an emphasis on the “faster" and “cheaper" factors.

The GOMX-3 project was a GomSpace milestone to develop a production method that reduces the development time. The six features exposed below summarize the critical factors of this methodology. It started due to a tight delivery schedule of less than a year. Besides, 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, are a baseline for most turn-key delivery projects [49, 141].

5.7.1.1 COTS Components

GomSpace uses 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 standard in CubeSats, allowing very compact and power-efficient designs. They are tested 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.

5.7.1.2 Distributed architecture

A distributed CubeSat architecture in self-contained modules is desired for a clear communication protocol between modules. GomSpace uses the CSP over the provided subsystem interfaces, like the Inter-Integrated Circuit (I2C). It brings two benefits; reduction in subsystem inter-dependency and standardization in the communication Interface Control Document (ICD).

The reduced subsystem inter-dependency is based on their self-contained nature, allowing engineers to develop and test them independently. Trade-offs are subsystem internal, reducing the satellite-level engineering load and the budget constrains to power, mass, and bandwidth.

The standard ICD is used through the CSP. This protocol is a light-weighted network-layer with a minimal memory footprint. It has a simple API inspired in Berkley sockets and supports connectionless and connection-oriented operations. The CSP can run on multiple physical layers in various architectures. Ground communications also use it, so for a subsystem, there is no difference in communications between the OBC, other subsystems, or the ground station.

5.7.1.3 Parameter System

The generic parameter system available in all GomSpace products permits operators to perform safe in-flight configuration changes. It is a RAM and FRAM based system that allows robust non-volatile storage of parameters. Modification of configurations, calibrations, and actions without a software update is also possible. It stores and downlinks telemetry data, and integrates the watchdog system.

The watchdog system resets and safely restores parameters, subsystems, or the entire system in case of a problem, ensuring the proper run of the firmware. At the subsystem level, if a problematic configuration occurs, an older and trusted configuration is automatically reset after a particular time. At the power supply level, the watchdog reboots the subsystem if it finds an error in the network communication bus. It reboots the entire satellite if no activity is recorded for ten minutes. All the critical subsystems have a watchdog that can be reset from the ground, and another that can reset subsystems or hardware automatically.

5.7.1.4 On-orbit Reprogramming

The company has shortened the CubeSats development time due to tight schedules, affecting mission software testing. Recognition of mission software errors at an early operation phase is crucial. Uploads of new firmware allow vital subsystems software reprogramming. The Group focuses the testing time on critical software elements and low-level interfaces. The firm puts low testing priorities on high-level mission functionalities, as its software upload system with the watchdogs can reboot defective subsystem configurations.

5.7.1.5 On-Orbit Calibration

Attitude and control systems testing, and calibration of subsystems, like the ADCS, require tons of time and particular facilities to simulate space conditions. The on-orbit calibration GomSpace implemented since the GOMX-3 project enables it 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 adjusting on-ground and on-orbit settings accordingly.

5.7.1.6 In-the-Loop Testing

This 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 subsystem checkout tests, satellite testing, and on-orbit operations [49, 141].

5.7.2 Product Development

The Group products are evolving as the next generation of communication Nanosatellites follow a specific development plan. It uses Nanosats as constellation routing devices and searches for future surveillance data extraction and compression. The company continuously optimizes the platforms through its IOD long-term technology development roadmap. Sponsored by programs under ESA, EU Horizon 2020, and the Danish Innovation Fund, the GomSpace development roadmap is directly affected by the four market trends below [105, 111].

- 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 spacecraft.
- Maturing mission assurance capabilities:
  - An Operational lifetime of at least five years.
  - High availability of space infrastructure to ensure high availability of end-user services.
  - Cybersecurity.
  - Constellation Management with a low operating expense.

The company development covers ISL, high performance propulsion technology, high gain antennas, new payloads, and platforms. The radio solutions portfolio increased with new X-band and Ka/Ku-band frequency ranges, complementing the existing VHF, UHF, and S-band, and more powerful SDR processing components. Focusing on the 6U and 8U platforms, the propulsion systems development works on fast and low-cost series productions of standard propulsion modules. GomSpace will launch a new cost-effective hybrid propulsion system program, becoming a pioneer of its kind.

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 company philosophy. The firm is developing the 12U and 16U CubeSat structure platforms as the market evolves. The power systems development include Modular and Deployable Solar Panels product range increases. New versions of power supplies and battery packs are also in progress, and the Group will introduce a sun-tracking Triple Deployable Solar Panels product range soon.

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 product improvement for deep-space missions. The Group will also implement the developed capabilities in LEO missions, improving their performance [107, 105, 111].

5.8 Operations

GomSpace is active in research, IOD, and partnership missions. While some operations have already finished, others are in progress or have not started yet. This section summarizes the company operations, where it took part mostly as a consortium member.

5.8.1 Past Operations

The past operations involve satellites that have already reentered the atmosphere, were lost, or their program was canceled.

5.8.1.1 GOMX-1

The GOMX-1 mission, also known as GATOSS, was an experimental 2U CubeSat sponsored by the Danish Innovation Fund. The Group managed the project, with the Aalborg University, DSE Airport Solutions, and Insero Software as partners. Its primary objective was to demonstrate aircraft tracking from space based on ADS-B signals reception through a sensitive SDR. Its secondary mission was to perform EO using a NanoCam C1U color camera.

The firm launched the GOMX-1 satellite on November 21, 2013, on a Dnepr rocket from Dombarovsky, Russia. It was deployed and operative, with only a stability issue. The satellite residual dipole moment was higher than expected, leaving the CubeSat stable only on two axes. Thus, the antenna was not always pointing downwards. The data from the primary payload received the desired aircraft signals with a better-than-expected helical antenna link budget. Its ADS-B payload continued working until May 7, 2014, when was power cycled and stopped responding because of an increased power draw. 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. This mission was successful as the GOMX-1 showed how CubeSats could contribute to developing new space-based services [33, 13].

The GOMX-1 is a standard 2U CubeSat that weighs 2.66 kg, and incorporates four 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 vital feature of the modular architecture is the CSP. This service-oriented network protocol makes all subsystems and ground segment autonomous nodes that can access and command resources in the network. The satellite components are described below [33, 13].

NanoMind A712: It is an OBC with up to 2 GB of data storage. It processes the ADCS subsystem data and interfaces with all the platform sensors and actuators. Its flexible software supports the mission.

NanoPower EPS: Subsystem formed by the NanoPower P110 solar panels and the NanoPower P31u power supply with batteries (see section 5.5.2 Power Systems).

NanoCom U482C: This half-duplex UHF transceiver operates from 435 MHz to 438 MHz. The system includes baseband processing and uses an I2C platform. The space link reliability improves through Forward Error Correction and Reed-Solomon coding.

ADCS: The 3-axis control system incorporates sun sensors and provides nadir and internal pointing with an accuracy of 10° using its magnetic coils.

SDR/ADS-B (Payload): The ADS-B receiver based on SDR technology collects sets of data packages transmitted periodically from the aircrafts' Mode-S transponders. The deployable helical antenna receives the signal with 10 dB gain at 1,090 MHz (see section 5.5.1.1 Aircraft Tracking ADS-B).

NanoCam C1U (Payload): It is a CMOS color camera for EO experiments with a resolution of 35 m at 600 km orbit altitude (see section 5.5.1.4 Optical Earth Observation).

5.8.1.2 GOMX-2

The GOMX-2 was a GomSpace project aiming to perform technological IOD. The 2U CubeSat had similar weight and architecture than its predecessor, the GOMX-1. Its mission objectives were to test de-orbit systems, to perform optical communication experiments and to evaluate new generation high-speed UHF transceivers and SDR receivers. The first two objectives were in collaboration with Aalborg U and the National U of Singapore, respectively. Its downlink data frequency was of 437.25 MHz. The Group launched the CubeSat on October 28, 2014, on the Cygnus CRS-3 cargo vehicle. However, shortly after the rocket lift-off, it exploded. It was supposed to reach the ISS and be deployed from the Japanese airlock. Its orbit should have been at 400 km with an inclination of 51.6°. The GOMX-2 was recovered undamaged, and the Science Center of Singapore exhibits it [129].

5.8.1.3 GOMX-3

The GOMX-3 was an IOD GomSpace project under the GOMX family and the IOD section of the ESA General Support Technology Program. The project incorporated the Aalborg U 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 -2 CubeSats, with the mission objective to demonstrate advanced satellite pointing while receiving L-band and ADS-B signals. In practice, the objectives were split into the three goals below.

- 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 satellite accomplished the goals. The attitude control showed 1-degree pointing accuracy with up to seven changes per orbit and target tracking. The satellite communications spot-beam was characterized, and the SDR spectrum was monitored in L-band. Finally, the CubeSat performed successful worldwide ADS-B aircraft tracking. Moreover, the Syrlinks executed high-speed X-band downlink at 3 MBps to ESA and CNES ground stations in Kourou and Toulouse, respectively [49, 34].

One of the most outstanding features of GOMX-3 development was its quickness. The Group designed, integrated, and launched the CubeSat in less than a year. This project time frame constrain was solved thanks to the collaboration between GomSpace and ESA. The latter developed a tailored ECSS for IOD CubeSats in LEO missions, reducing the number of full requirements from a standard ECSS, and converting them into applicable, guideline, or not applicable. Furthermore, GomSpace created new methods to reduce development and testing time by focusing on payload and subsystem-level (see section 5.7 Production System).

The company launched the GOMX-3 from Japan on August 19, 2015, on-board the HTV-5 rocket. After arrival at the ISS, Nanoracks deployed it on October 5, 2015. The satellite transmitted the first beacon to the Aalborg ground station with healthy telemetry, steady beacons, full battery, and de-tumbled attitude. It passes about five times a day over the ground station with an average pass length of 7.4 min. The first 37 minutes of contact confirmed the satellite healthiness in power, communications, and attitude determination & control. Then, engineers checked the payloads with the same successful results. They included the advanced ADCS, the ADS-B receiver, the NanoCom SDR and the Syrlinks EWC27 X-band transmitter.

This 3U CubeSat incorporates may COTS components on its bus. The bottom 1U contains satellite subsystems; the middle 1U hosts the ADCS system, the NanoCom SDR, and the ADS-B receiver; and the upper 1U carries the X-band transmitter and ADCS support hardware. Figure 5.4 shows the internal layout of the GOMX-3. The communication between bus components is executed through CSP. The most important components are described below [49].

NanoPower EPS: It is an EPS by the NanoPower P31us power supply and the NanoPower BP4 battery pack with four Li-Ion series cells (see section 5.5.2 Power Systems).

NanoMind A3200 OBC: The mission OBC stores mission-specific commands and no-ADCS telemetry for downlink (see section 5.5.4.1 NanoMind A3200).

NanoCom AX100: The primary RF UHF communications method is in-orbit adjustable in frequency, bit-rates, and data encapsulation (see section 5.5.3.1 Space Segment).

NanoMind A3200 ADCS: The OBC dedicated to ADCS filters sensors' data inputs, applies control, and commands actuators for stability (see section 5.5.4.1 NanoMind A3200).

NovAtel OEM615 GNSS: It is a GNSS receiver compatible with GPS and GALILEO.

AstroFein RW-1: It is a Four-reaction-wheels device assembled in a tetrahedron and controlled by the AstroFein WDE driver board.

NanoUtil Interstages: It is made by nine PCBs that collect ADCS data from sensors and control the antennas' deployment. It hosts FSS with a 2-axis sun vector measurement.

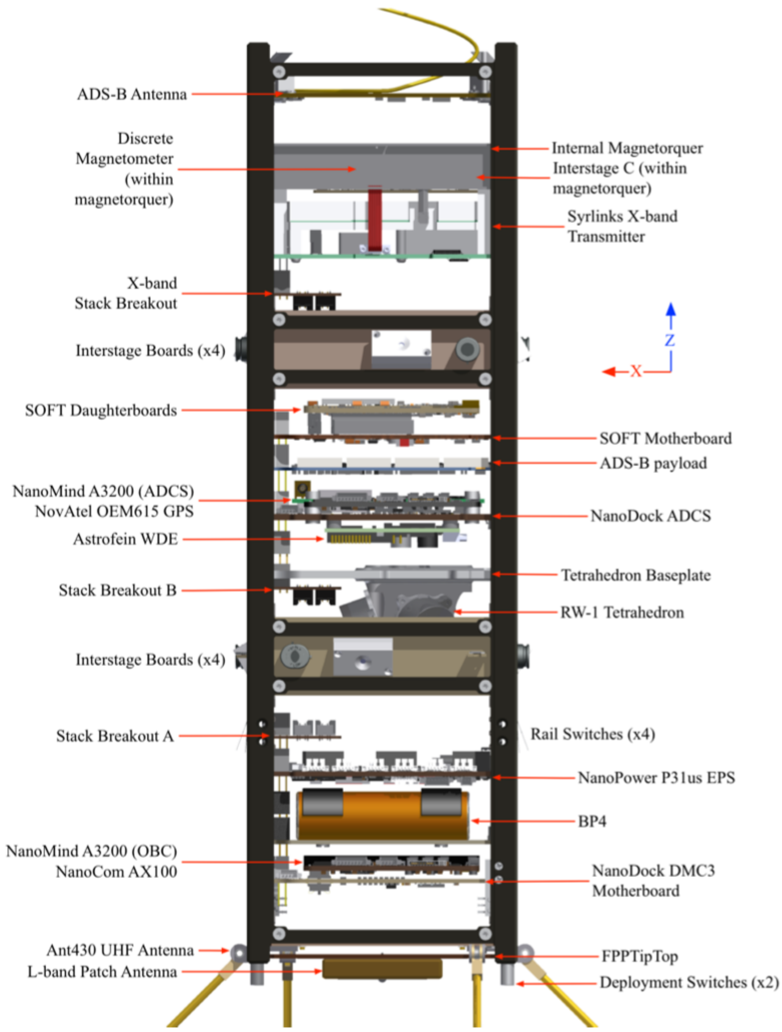


Figure 5.4: GOMX-3 internal layout. *Image Credit: Gerhardt et al. [49].*

NanoCom Ant430: It is a four-canted, deployable, turnstile, and omnidirectional UHF antennas (see section 5.5.3.1 Space Segment).

The list below shows the mentioned GOMX-3 payloads [49].

NanoCom ADS-B: It is an 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 5.5.1.1 Aircraft Tracking ADS-B).

NanoCom SDR (SOFT): Based on the Xilinx Zynq Z7030 FPGA, it can be augmented with up to three Front-End Modules to interface with multiple antennas. It uses an L-band patch antenna on its -Z face (see section 5.5.1.3 Software Defined Radio (SDR)).

Syrlinks EWC27: The Syrlinks X-band transmitter is capable of bit rates up to 100 Mbit, but only 3 Mbit are downlinked from a GOMX-3 X-band patch antenna on its +Y face.

The Nanosat working life was extended about six months until its reentry on October 10, 2016. In addition to the accomplished mission objectives, the GOMX-3 achieved extra ones. Novel ADCS algorithms reducing the aerodynamic drag extended its life. 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 obtained aircraft-measured wind data [34]. The project gave GomSpace four valuable lessons lo learn [49].

- **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 did not allow enough testing time. On-orbit calibration of the ADS-B and X-band downlink software debugging was crucial.
- **The usefulness of easily 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.

5.8.1.4 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 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. Future spacecraft should carry this independent module to ensure proper disposal after ending their service lifetime. The principal 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 [41].

5.8.1.5 SAGAS

The Satellite Augmented Global Aircraft Surveillance feasibility study involved the ESA and six other companies, including Airbus 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 ended in September 2018 with a list of candidate-services based on ADS-B integrated applications [39].

5.8.1.6 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 feature of the satellite's software will be changed on-the-fly without significant mission risks. GomSpace had to deliver the core-satellite platform, but they have lost importance and involvement in the project [38].

5.8.2 Current Operations

At the moment GomSpace is involved in many missions as part of a consortium. The Group has constructed ten CubeSats that are operational on April 2020, but only owns three of them. They pertain to Aistech (two 2U), UnseenLabs (a 6U), Sky and Space Global (three 3U), and Colombian Air Force (a 3U) [210].

5.8.2.1 GOMX-4

The GOMX-4 is an IOD mission of a two 6U CubeSats constellation based on the successful GOMX-3 project. The GOMX-4A is sponsored by the Danish Defense Acquisition and Logistics Organization, while the ESA IOD program funds the GOMX-4B. The primary mission objective is to demonstrate ISL communication between constellation satellites. While both satellites fly at 500 km in SSO, one CubeSat captures data from a targeted region and later transmits it to the other if their distance goes from 200 km to 4,500 km. Finally, the receiver satellite downlinks the data to the Aalborg ground station. Individually, the satellites have other mission objectives. The GOMX-4A monitors Greenland and the Arctic region, capturing images and data from ships and airplanes through AIS and ADS-B respectively. The GOMX-4B seeks IOD of orbit control maneuvers based on cold-gas propulsion, hyperspectral imagery, high-accuracy attitude determination, and COTS behavior in space [219].

GomSpace launched both satellites on February 2, 2018, onboard the Long March 2D-Y13, to be deployed from the PSL-P. The first three operational weeks helped to check optimum subsystems' behavior, while the following four did a similar task with the payloads. Due to a difference in deploying time, the satellite orbits were slightly distinct, and engineers noticed an increased drift between them. Hence, the propulsion system in the GOMX-4B and differential drag surfaces in both CubeSats corrected the orbits. The Nanosats fly in tandem, with the distance between them reaching 4,500 km to determine the ISL limits.

The satellites have a 6U CubeSat structure with similar platform components but different payloads. The common subsystems are the **NanoMind A3200** OBC, the EPS **NanoPower P60**, the ADCS, and two UHF **NanoCom AX100** and S-band **NanoCom SR2000** ground communication links. TThe NanoMind A3200 and the NanoCom AX100 subsystems were already onboard the GOMX-3 satellite, but the others bring relevant platform updates. The upgraded version of the ADCS uses external gyro sensors, powerful reaction wheels, and modified star tracker technologies, besides the successful GOMX-3 components (see section 5.5 Satellite Payloads and Subsystems) [219].

The **GOMX-4A** has in-flight-proven **AIS** and **ADS-B** receiver payloads. It incorporates a 3 Mpx **NanoCam C1U** to monitor regions of interest like Greenland and the Arctic. It carries **ISL** components to perform its primary objective, including two patch antenna at every 2U unit end and an SDR. The latter can use two innovative modulation techniques for short and long distances. The firm included some dummy masses to equalize the mass difference with the GOMX-4B, facilitating dynamics and behaviors.

The **GOMX-4B** incorporates the GomSpace cold-gas **NanoProp 6U Propulsion** module as a primary payload to demonstrate orbit control maneuvers. The GOMX-4B has identical

ISL payload components than the GOMX-4A. As the duration of its payload demonstration phase should last about six months, it incorporates an external transceiver for the ISL SDR to acquire **ADS-B** data in a future commercial phase.

Moreover, the GOMX-4B CubeSat hosts three secondary technology IOD payloads. The **Cosine HyperScout camera** is a miniaturized hyperspectral imager with a real-time data processing unit. It provides a 70 m ground sampling distance at 500 km using its three-mirror anastigmat telescope. The **ESA Chimera** electronics board incorporates twelve separate computer flash memories, whose performance in space is being monitored by a space-qualified chip. This cheap COTS is tested under a radiative space environment. An **ISIS Star Tracker** is examined to provide high accuracy in attitude determination [219, 36].

By the end of 2018, the GOMX-4 mission completed its objectives successfully. The two satellites are still operative, with an expected lifetime from three to five years. The GomSpace Luxembourg subsidiary is in charge of the mission exploitation and its operations [36]. While executing the mission, new challenges raised. Engineers have to address them in order to develop up-scaled constellations in future missions [219].

- GomSpace optimized the verification processes, reducing development cost and time with the Proto-Flight Model approach.
- Orbital data was inaccurate during LEOP. The satellite should include an independent GPS implementation, involving higher complexity and power consumption at LEOP.
- Communications to a ground station at the same time and frequencies by both CubeSats involved simultaneity challenges. 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 telecommands, telemetry actions, and a data delivery interface for clients.

5.8.2.2 RACE

The Rendezvous Autonomous CubeSats Experiment is a mission under the ESA IOD program. This project aims to develop new CubeSats technologies for proximity operations, including in-orbit rendezvous and automatic docking. The mission comprises two 6U CubeSats that will perform close flyby around uncooperative bodies. GomSpace is the leading company of the mission consortium, delivering the two 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 [113].

5.8.2.3 Discoverer

A consortium of eight partners runs the Discoverer project, including GomSpace. The EU Horizon 2020 program funds it with EUR 5.7M, aiming to find new technologies to drastically redesign EO platforms and make them sustainable operative at low altitudes. Its targeted satellite altitude at VLEO provides more advantages than drawbacks (see section 2.3 LEO and VLEO orbits in EO).

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, 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.

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 to demonstrate aerodynamic attitude and orbit control maneuvers. Its two payloads will investigate interactions between different materials and the orbit atmosphere. Steerable fins containing the materials can vary their geometry and angles of incidence. This satellite incorporates an Ion and Neutral Mass Spectrometer that gauges the flow composition, density, and the thermospheric wind velocity. GomSpace is the leader of the work package that develops the IOD CubeSat [139, 165].

Another way to neutralize the aerodynamic drag challenge is with a propulsion force. The project aims to design, build, and test an air-breathing electric propulsion system that uses the orbit atmosphere gas as a propellant. Moreover, the orbit atmosphere can help to control the attitude of the spacecraft. Active aerodynamic control maneuvers 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. It is highly multidisciplinary, ranging from surface chemistry to control engineering. It intends to develop critical technologies from concept (TRL 1-2), through proof-of-concept, and on to validation (TRL 4-5). Discoverer will eventually define roadmaps to serve as guidelines for commercializing these innovative technologies, making EO at VLEO a reality [165].

5.8.2.4 DOC

A consortium of seven companies runs the Demise Observation Capsule project, lead 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 measures after the final separation stage, collecting velocity, acceleration, GPS position, pressure, and temperature data. A camera will record the entire descent. GomSpace contributes to the project by designing and delivering the capsule avionics and sensors [221].

5.8.3 Future Operations

GomSpace has already signed contracts for new projects. Here are the most significant.

5.8.3.1 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 innovative Nanosatellite constellation capabilities regarding high-speed communication links and high levels of maneuverability. It will consist of two 12U CubeSats with similar components than the GOMX-4 but increased power handling and reliability. With its launch scheduled for 2021, the GomSpace and ESA contract only guarantees the project development for Phase A during 2019. It covers EUR 300K, leaving the subsequent additional contracts subject to the project progress. Some payloads and subsystems that the CubeSats will host have been announced [64].

- **Propulsion systems** developed by ThrustMe, ExoTrails, and GomSpace Sweden.
- **Two X-Band** high-gain reflection **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.
- A lightweight **EO imager** developed by Tartu Observatory.
- **AI** on spacecraft developed by AIKO.
- A **Ka-Band ISL** developed by GomSpace.

5.8.3.2 A&M

GomSpace is the sole deliverer of the space-based business infrastructure from Aerial & Maritime Ltd (A&M). Due to GomSpace's partial ownership of A&M, this project can almost be considered internal. The objective of the initial eight 3U CubeSats will be to track aviation and maritime traffic between 37° north and south of the equator. Thus, each of the Starlings 1 to 8 will equip an ADS-B and an AIS receivers. The launch of these CubeSats should occur during 2019 onboard the Virgin Orbit's LauncherOne [135]. The Group 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 [102].

5.8.3.3 M-ARGO

The Miniaturized Asteroid Remote Geophysical Observer (M-ARGO) mission will develop the first-ever CubeSat for asteroid rendezvous and proximity resource identification. The latter technique characterizes the asteroid physical properties, like its shape, surface, or mass. It aims to assess the potential for resource exploitation, checking the asteroid composition and hydration. GomSpace signed a EUR 400K contract to develop the mission Phase A preliminary design, spacecraft, and implementation planning. The 12U CubeSat will host state-of-the-art 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 [67, 139].

The data collected during six months of measurements will return to the Earth using an X-band (8.4 GHz) 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 [37].

With the launch expected in 2023, it requires the following development work contracts for the next phases. GomSpace will develop the project in its Luxembourgian subsidiary, and the Politecnico di Milano will support the company with deep-space mission analysis and navigation of low-thrust trajectories associated with electric propulsion [67].

5.9 Most important Partnerships

Many companies cooperate with GomSpace in order to achieve similar objectives. The partnerships developed are crucial for the company's growth. The most important distribute into three groups, depending on their purposes. Those are the partnerships to develop IOD projects, spin-off strategies, or large CubeSat constellations with customer companies.

5.9.1 IOD Partnerships

The most characteristic IOD GomSpace missions are under the GOMX program. They were possible thanks to the Group collaboration with partners. Their involvement in the projects could go from monetary investments to technical support and collaboration. The essential partners regarding IOD are below.

5.9.1.1 The European Space Agency

The European Space Agency is the biggest GomSpace partner. Their first cooperation dates from 2014 with the **GOMX-3** CubeSat mission. The ESA contributed to the project actively, providing financial investments, ground station capabilities, and technical assistance. The successful cooperation led to the **GOMX-4** project, where they were mostly involved in the GOMX-4B CubeSat. Both parts have announced a new collaboration for the **GOMX-5** mission development. The Group participates with the ESA in other Nanosatellite projects like the SAGAS, OPS-SAT, RACE, DOC, or M-ARGO (see section 5.8 Operations). Furthermore, both parties sealed a contract to develop the MCOP project, aiming to offer constellation operations services to small satellites.

5.9.1.2 The Aalborg University

The Aalborg University has worked hand-by-hand with GomSpace in projects of the IOD GOMX family. It contributed to the satellite payload development and other technical issues. The firm provides internships and working opportunities to the university students due to their close relation, based on the physical proximity between each other and the alma mater status of the university for the company founders.

5.9.1.3 The Danish Defense

The Danish Defense has partnered with GomSpace to support them financially and technically to develop the GOMX-4A. This mission aims to monitor Greenland and the Arctic region by capturing images, AIS ships and ADS-B airplanes data. The partnership is imperative for the Group as it is the first with a governmental entity.

5.9.2 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 more valuable than a subsidiary forming part of a large business. It takes assets, employees, product lines, or technologies from the parent company for an amount of money. As the subsidiary grows, GomSpace intends to dilute its ownership percentage to transform the spin-off interests into excellent customer relationships [27].

5.9.2.1 Aerial & Maritime Ltd (A&M)

The first and most valuable Group's spin-off partnership is with Aerial & Maritime Ltd. Established in 2015, A&M aims to track aircraft and ships using in-orbit ADS-B and AIS technologies. They started with a USD 10M GomSpace-developed eight satellite constellation for equatorial coverage, the Starling 1-8. The next company step is to launch a same-purpose global constellation that would require about 80 CubeSats. This new project is worth about USD 100M, and the company and A&M agreed on an MoU in June 2018 to sign an order contract. GomSpace 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 firm totals. [205, 48, 105].

5.9.2.2 BeamWatch

GomSpace secured an innovation project with the Danish Trica Fond from the Innovation Fund Denmark. The BeamWatch project aims to monitor satellite performance of communication satellites from a Nanosat. It will predict and measure the communication quality from over 400 satellites, ensuring that they do not interfere with each other and only send out signals in their respective designated areas. Software tools onboard the satellites will predict the readings and compare with the actual ones to report any divergence. GomSpace is preparing this project to be spin-out [100, 109].

5.9.2.3 Singapore Technologies Electronics

Aiming to get constant communications between aircraft and airports, GomSpace started a research collaboration with the CAAS and the public-listed Singapore Technologies Electronics. It would provide VHF connectivity between airlines and air traffic towers via satellite reducing aircraft safety distances from 80 to 5 NM [109]. The Danske Bank analysts Stjerngren and Elvind [205] believe that the Group would likely develop a joint-venture relationship with the latter company, similar to A&M. The firm will most likely be the supplier of an eventual commercialized solution resulting from the research.

5.9.3 Large Constellation Partnerships

Most GomSpace sales and revenues come from three large customers; Aistech Space, Kleos Space, and Sky and Space Global. The separate agreements with these clients share an objective to develop large EO satellite constellations. The reason behind considering them partners is that these contracts require collaboration from both parties to develop new customized technologies. Thus, GomSpace learns through the process and gains experience [105].

5.9.3.1 Aistech Space

The Group sealed a framework agreement in 2017 with the Spanish company Aistech for a purchase of 100 CubeSats until December 31, 2021, with a total value of EUR 12.5M. However, there are no purchase commitments in the agreement, with specific contracts being placed when there is a purchase order. The firm has received two orders for 10 Nanosats worth EUR 1.24M.

5.9.3.2 Kleos Space

GomSpace won an initial EUR 2.4M order to develop the first Kleos IOD mission, the Kleos Scouting Mission, a keystone for an eventual global high capacity constellation. The Luxembourgian company aims to deliver global activity-based intelligence and geolocation as-a-service to guard borders, protect assets, and save lives. These four 6U CubeSats already passed the Critical Design Review and should get launched on May 28, 2020 [138, 122].

5.9.3.3 Sky and Space Global

In 2017 Sky and Space Global and GomSpace entered a procurement agreement to develop and deliver 200 Pearl constellation CubeSats. The initial contract, with a EUR 64.5M value, would have delivered the satellites over four years. GomSpace also delivered three 3U Nanosats from a previous IOD constellation, the Diamonds. The firm received EUR 4.28M for it and the start of the Pearls. However, by the end of 2018, the Group did not earn the expected overdue invoice payments of SEK 33.317M, affecting the company's economy negatively. Eventually, and after a Sky and Space Global cash flow situation assessment, GomSpace got SEK 20.819M corresponding to the Critical Design Review invoice [105].

GomSpace and Sky and Space Global had to update their situation with a new agreement to design 6U CubeSats ("6U Agreement") and to change the original Pearls agreement. In the former, GomSpace will deliver a batch of eight 6U CubeSats by Q1 2020 worth EUR 5.3M. It would deliver an additional optional batch of eight Nanosatellites in H1 2020, worth EUR 3.8M. The CubeSats will use assets developed under the Pearl Agreement. The negotiations to modify the original 2017 agreement were supposed to finalize before mid-June. However, both companies accorded to extend the negotiations until August 31, 2019 [111, 150].

5.10 Financial Status and Risks

This section contains GomSpace's financial performance and risks. Both topics are closely related, as many of the company risks are financial. The monetary amounts are in SEK, with the exchange rate on June 1, 2020, showing that SEK 1 was equivalent to EUR 0.096 and USD 0.107.

5.10.1 Financial Performance

To illustrate the financial performance of the Group, Tables 5.9 and 5.10 present its financial key figures and ratios. The last available Annual Report shows 2019 results [112]. The information is presented in columns with the yearly results from 2019 to 2014.

Net revenue and gross profit decreased in 2019 compared to 2018 by 11% and 53%. It finalizes a tendency of 5 years with increased values. The gross margin also decreased from 25%

Table 5.9: GomSpace Group AB financial key figures in T.SEK (Thousand of SEK). *Adapted from GomSpace Group AB [112, 107].*

Key Figure	2019	2018	2017	2016	2015	2014
Net Revenue	136,263	153,384	96,405	54,142	34,087	26,645
Gross Profit	17,994	38,549	26,884	25,201	17,195	11,029
Operating Profit (loss)	−113,856	−116,601	−67,610	−14,510	−2,357	1,762
Profit Share from Associates	−25,967	−2,112	4,591	21,386	-	-
Net Financial Items	−6,708	−4,098	−3,496	−1,389	−766	−178
Profit (loss) before Tax	−146,531	−122,811	−66,515	5,487	−3,123	1,584
Profit (loss) for the Period	−151,663	−112,498	−53,989	8,981	−2,369	1,224
Intangible Assets Invest.	14,998	65,477	38,908	21,848	5,489	747
PPE Invest.	6,953	25,349	18,500	6,447	543	528
Total Assets	436,753	608,542	313,069	209,093	30,067	19,051
Equity	295,682	441,843	185,315	146,106	13,816	7,721
Total Liabilities	141,071	166,699	127,754	62,987	16,251	11,330
Working Capital	−20,522	6,010	23,606	−7,399	−13,821	−4,580

in 2018 to 13% in 2019. The operating profit, a loss for the company, slightly got lower by 2%. Even if still a loss, it reflects a tiny improvement in the profit that was never observed. However, the operating margin went from -76% to -84%. Thus, the 2019 period result was a net loss of SEK -151.66M. It represents 26% more than in 2018, with a net margin decreasing from -73% to -111%. The tendency is highly influenced by the resources overcapacity resulting from putting on hold the Sky and Space Global project at the beginning of 2019, and lower-than-expected order intakes. The project was excluded from the order book, resulting in a reduction of employees that showed its effect during Q4 2019. However, the company achieved a positive momentum at the end of the year with order intakes catching up.

The yearly tendencies of the key figures and ratios are similar. Even though the revenues have increased since 2014, the gross, operating, and period profits have decreased. It is observed with decreases in gross, operating, and net margins. The three graphs in Figure 5.5 illustrate the tendencies of order intakes, net sales, and operating profit in recent years. Even if the net sales decreased by 11% (Net Revenues), the operating profit slightly improved, and the order intake increased by 49% to SEK 192.4M.

Nonetheless, GomSpace experienced an inflection point in 2019, with positive tendencies slowing down, or down-turning, and negatives speeding up. The last company's long-term goals aimed 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, with recessions in both values at the end of 2019.

Investments in Property, Plant, and Equipment (PPE) are related to new production equipment and facilities, and continually increased until 2019. The investments in intangible assets account mostly for in-house development of portfolio projects or improvements in constellations management. They have experienced a yearly increase of about 50% until 2019. Then, the company saw less invested money in both categories due to GomSpace's difficult situation, decreasing about 75%.

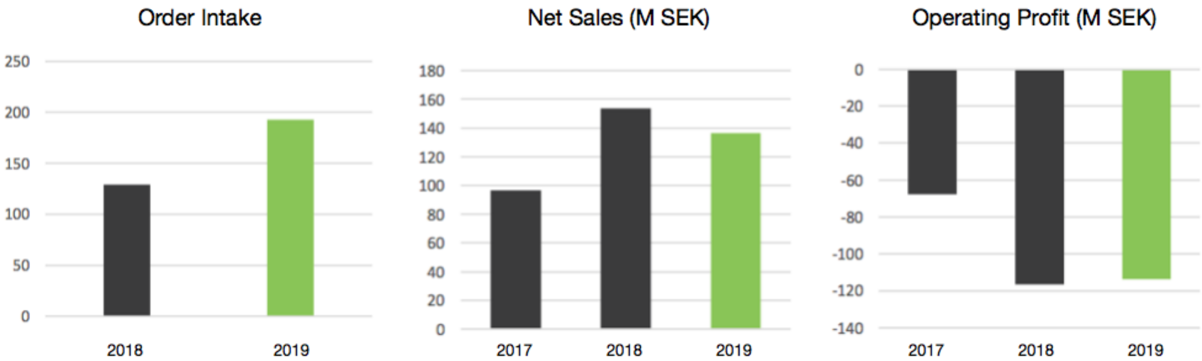


Figure 5.5: Order intakes, net sales, and operating profit in recent years (M.SEK). *Adapted from GomSpace Group AB [112].*

The associates' profit share is a result of GomSpace partially owned Aerial & Maritime Ltd. A&M results have turned from profit to loss over the years. The net financial items have negatively increased over time, resulting in a negative effect on profit. A&M unsuccessful financial inducement lead GomSpace to a strategic business plan review, writing down SEK 23M in the subsidiary.

Table 5.10: GomSpace financial ratios. *Adapted from GomSpace Group AB [112, 107].*

Ratio	2019	2018	2017	2016	2015	2014
Gross Margin	13%	25%	28%	47%	50%	41%
Operating Margin	−84%	−76%	−70%	−27%	−7%	7%
Net Margin	−111%	−73%	−56%	17%	−7%	5%
Invest. Capital Return	−35%	−18%	−17%	4%	−8%	6%
Equity Return	−41%	−36%	−33%	13%	−22%	18%
Equity Ratio	68%	73%	59%	70%	46%	41%
Basic earning per share (SEK)	−2.90	−3.93	−2.09	0.62	-	-
Diluted earning per share (SEK)	−2.90	−3.93	−2.08	0.62	−0.17	0.09
N. of Shares by end of period	52.275M	52.275M	26.257M	24.507M	-	-

The total shareholder's equity by each period's end has continuously increased thanks to the share issues. A good comparison is between 2018 and 2019, when the number of shares is equal, but there is a loss of SEK 146.2M in equity. The return on equity has decreased yearly, showing a significant downturn from 2016 to 2017. The liabilities increased continuously under the company's will for expansion, but at lower levels than equity, and decreased in 2019. Regarding these two key figures, the total firm assets have risen exponentially until 2019, while the return on invested capital has decreased. Nonetheless, the equity ratio has established a value of around 70% since 2016. It shows a balance between equity and profit increases based on share issues and sales.

Both earnings per share represent the profit obtained per basic or diluted share. Their values are negative and decreasing over the years, showing the net losses the company is experiencing and the aggravation of them. Still, GomSpace expected these losses while the company expands, and 2019 values improve the 2018 results.

Finally, the working capital shown in Table 5.9 represents the company's liquidity. The 2018 result has decreased compared to 2017 but is still positive, while 2019 shows the most significant debt ever for GomSpace. Trade receivables and contract work negatively affected it, mostly referring to the missed payment of overdue invoices from Sky and Space Global. Other liabilities positively affected the capital, increasing due to the related costs of the rights issue. The 2019 results show a negative value, with a capital decrease in about SEK 26M compared to 2018. Inventories, trade payables, and other liabilities affected this figure negatively. The overcapacity of employees resulted in product manufacturing for the stock, increasing the inventories. The costs related to the rights issue from 2018 affected negatively through liabilities, while contract work and trade receivables, based on the payment from Sky and Space Global for the Critical Design Review, benefited the working capital.

5.10.2 GomSpace Risks

GomSpace is susceptible to many risks. Its position in the NewSpace sector makes the company vulnerable to the uncertainties of expansion and growth. Its risks are classified between financial and industry risks.

5.10.2.1 Financial Risks

They are risks that involve capital, including credit, interest, foreign currency exchange, and liquidity risks. GomSpace is exposed to these risks because of its activities but manages them by following policies approved by the Directors. The company is not involved in speculation of financial risks. The financial risks are presented below [107].

Credit risk occurs when a counterpart does not 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 1, 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 come from a few large customers. There is a risk that these customers will not meet the financial requirements due to a lack of financial resources or other circumstances beyond the firm's control. GomSpace assesses customer credit quality and monitors their receivables to ensure financial health. Besides the risks of Sky and Space Global, GomSpace's evaluation of trade receivables risks is low.

Interest risk: They are present due to GomSpace loans, carried out at variable interests. The company states that a change of +/-1% had 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. They also operate in SEK because of their registration in Sweden. Thus, changes in foreign exchange rates of DKK, USD, and EUR to SEK has effects on results and equity, which the Group has estimated for 2019.

Liquidity risk: It relates to a lack of funding and adequate financial liquidity to meet short-term financial demands. Due to GomSpace's early development stage, the generated cash flow has not satisfied the working capital requirements. This situation may prevail, eventually making the company cancel or postpone projects if no external financial sources arrive. The Group manages and monitors funding and liquidity, ensuring availability through cash management and borrowing facilities. It continually maintains cash assets and 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. Since 2015, the firm's primary long-term financing comes from a Vækstfonden loan under the EU's InnovFin SMV Program. However, payment obligations should be settled through cash inflows from operating activities and proceeds from capital injections.

5.10.2.2 Industry Risks

GomSpace manages risks that may be related to the company but would affect its business, financial position, and future results. The most substantial risks are below [107, 205, 105].

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, with better preparation or financial conditions. The firm could compete on other terms, but the challenge would be to secure orders and profitability based on technology development and loyal customers. Modularization and production automation supports growth in the Nanosat industry. GomSpace mitigates this risk by monitoring and reevaluating the business with quarterly forecasts and yearly 5-year plans.

Key personnel: Skilled personnel is essential for the proper growth and development of GomSpace to reach future success. If the company cannot attract, retain, or replace skilled personnel, ongoing projects, and development plans may be interrupted. That would bring an adverse impact on its business, financial position, and future profits. Thus, the Group tries to keep itself an exciting workplace by selecting its locations in attractive areas.

Risks relating to the quality of the product: GomSpace aims to provide quality products, but the company's quality standards and the customers' may not meet.

A wrong or underachieving product development that does not meet market standards may negatively affect the Group's business, financial position, and future profits. Its Quality Assurance department ensures the performance of the product quality control plus its periodic registration and monitoring. Besides, the Product Innovation Board validates ongoing and future development projects.

Market competition: Only one competing company is publicly traded, while others provide limited information. Thus, the Group market share is unknown, as well as the competitors' positions, finances, and technologies. New actors and technologies, superior to GomSpace's, may arise, even threatening the market from other sectors. The market could experience high competition on price and quality, and failure in development could lead to a loss of offers and market share. With its proven sector experience, the firm tries to be close to its customers and aims to offer a broad product portfolio.

Risks relating to customers: GomSpace has agreements with a few large customers (Sky and Space Global, Aistech, A&M), but only specific orders provide revenue. There is a risk of customers not placing orders or not fulfilling their requirements. The company could also lose payments if it does not meet the milestone requirements. As specified in the *credit risk*, GomSpace mitigates this risk by taking out debtor insurance and evaluating the customer funding situation. Furthermore, the company seeks to enter milestone payments with positive cash flow.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 business strategy and become unsuccessful. Subsidiaries' acquisition aiming company expansion may have many economic and logistic risks. Even if the process is successful, integrating the subsidiary may bring more problems than successes, eventually closing and generating more expenses and obligations. GomSpace mitigates the impact of these situations by including in their forecasting an exit strategy for closing down a subsidiary.

Execution risk: The most substantial risk for GomSpace is the execution. The increase in production and industrialization is a risky phase in any company growth profile. However, the actions taken in the facilities predict a highly probable successful transition [205].

Launch of the satellites: The satellite launches could be a constraint for the company's growth. The sector requires a launch cost reduction to keep in concordance with the Group's growth. Nonetheless, their projections do not expect launch capacity constraints to be an issue due to the CubeSat launching sector's current development [205].

6 | Aistech Space Case Study

This chapter will present the Case Study of Aistech Space. Also known as only Aistech, its name is the acronym of *Access to Intelligent Space Technologies*. They define themselves as a geospatial intelligence company that provides valuable information about the Earth from space. With their Nanosatellite network, they intend to democratize the access to space knowledge and offer added value to costumers in order to improve their decision-making process. Their focus is on remote asset management of vessels, EO, and aviation tracking and surveillance through AIS, thermal imaging and ADS-B, respectively [9]. The information is organized under the History and Overview of the company, Business Statement and Philosophy, Ownership and Employees, EO Market Segment and Services, Operations and Satellites, Most important Partnerships, and Financial Status and Risks.

6.1 History and Overview of the company

Carles Franquesa Giner and Guillermo Valenzuela Ramos founded Aistech Space in 2015. They registered the company in the Barcelona Commercial Register on August 8, 2015. Franquesa was listed as a sole administrator while Valenzuela was the joint and several attorneys. The firm had its tax residence at the UPC Park of Castelldefels, Spain, and a capital of EUR 3,006. The declared objectives were to design, manufacture, operate, and commercialize an own satellite network, and to manage and commercialize the collected data in combination with external [172].

The company description developed into a more detailed one. Franquesa wrote in his LinkedIn profile that the business aimed *"to become a worldwide Big Data Analytics firm"* by doing the stated tasks. *"AIS signals and frequencies from space"* were the principal data source, leaving the ADS-B and thermal imaging technologies still undiscussed. CubeSats would form the satellite network, developed in partnership with the UPC, and *"launched by external companies"*. Aistech would develop and own software able to manage the enormous volume of captured data and *"offer customized information to clients"* [46].

By October 2015, Aistech raised its capital to EUR 10,006 [125]. They received a grant split into EUR 35,000 in 2015, EUR 10,000 in 2016, and EUR 5,000 in 2017 from Barcelona's town hall to carry out a project called *"AIS Booster Decollisioner"*. They estimated the project for a total cost of EUR 1,365,980 [11].

Between February 22 and 25 of 2016, the company attended the Mobile World Congress under the *Four Years From Now* program. It helps entrepreneurs get inspired and develop connections with founders and investors. The took part of Aistech in the congress was thanks to Barcelona's town hall initiative *Barcelona Activa*. Together with the ESA Business Incubation Center, *Barcelona Activa* helped the company with fund-raising, grants counseling, and networking [17]. Aistech was allegedly said to have started with a EUR 100,000 capital from the founders' funds and a *Barcelona Activa* loan. They started offering its ADS-B capabilities for aviation tracking and position management. With the company's web page inaugurating in July 2016, the firm stated in it that they were planning to have a 25 satellite constellation by 2020 with full Earth coverage starting in 2017 [125, 142].

The first Aistech test occurred in May 2016, with a high-altitude balloon carrying its first CubeSat to an altitude of 30 km. The Aistecsat-1 successfully captured ADS-B aircraft data and tested its internal systems. The results became a solid base for Aistech to develop and improve the following IOD CubeSat, the precursor of their constellation. The success of the first mission helped them raise EUR 300,000 in their first private investment round. However, their next IOD mission and ground infrastructure development required about EUR 1M [223, 7].

On December 14, 2016, the Galician Innovation Agency published a resolution awarding financial aids to the creation, development, and consolidation of investigation mixed units for four years. One of them involved Aistech Space and the Centro Gallego de Innovación Aeroespacial (CINAE) to *"manufacture a satellite constellation for observation, communication, and maritime and aerial control"*. The unit would work together on a satellite platform that would have four years of reliability based on automatized assembly lines and quality. Aistech would focus on the payload integration while the CINAE would work on the mission and platform. They estimated the total project budget at EUR 2.327M, of which the Galician government contributed with a 30% (EUR 0.7M). The press release at the end of 2016 showed that Aistech Space counted with over 30 private investors and raised funds over EUR 2M. They were preparing a second private and public investment round to earn about EUR 2M more [4, 5].

The company took a significant turnover in 2016 with the Galician government subventions and an eventual 2017 headquarters relocation to Nigran, Galicia. By the end of 2016, Aistech placed an order on GomSpace for the delivery of their second CubeSat mission platforms and payloads. The EUR 200k order was for a mission of 2 sibling satellites, launched from different providers. The Aistechsat-2 and Aistechsat-3 (Danu Pathfinder 1) IOD satellites incorporate ADS-B receivers and AIS receivers for bidirectional communication [139, 114]. Aistech's relationship with GomSpace developed to the point that in June 2017, both companies signed a 100 Nanosatellites delivery MoU. The plans of Aistech changed with their vision of 25 constellation satellites increased to 100 by 2022. The CubeSats would include ADS-B, bidirectional AIS, and multispectral space imaging [8]. In September, the MoU became a EUR 12.5M binding Framework Delivery Agreement. Aistech expected GomSpace to deliver the first EUR 0.5M batch order of 4 CubeSats in 2018 [101].

Aistech also sealed agreements with GomSpace associated company A&M in 2017. Their 5-years mutual Data Service Agreement would begin in 2018. It would provide both ADS-B and AIS data access from the other's CubeSat constellation. The agreement value would vary depending on different data packages options, laying between EUR 1M and EUR 8M for A&M, and between EUR 1M and EUR 4M for Aistech [116].

The company opened its third office during 2017, in Luxembourg, thanks to the country investment in the NewSpace sector. Aistech Space counted with 17 employees and secured nearly EUR 3.5M in 3 private investment funding rounds [144, 214].

The year 2018 continued with prosperous company development with the signing in April of an MoU with Tracasa. This company specializes in public administration modernization through technical solutions, territory engineering, and cartography. The agreement set the first step of a future collaboration to develop services and products based on thermal and multispectral images obtained by Aistech [208]. They also signed a new contract with GomSpace under their agreement for EUR 1.4M. The first part added 6 CubeSats to a 4-platform order placed in September 2017. The second part agreed on the AIT of those 10 Nanosatellites, named DANU. Both members must perform the activities in the contract within a year. Aistech expects to launch the first 10 CubeSats of the constellation by mid-2019. These 10 CubeSats will equip ÅAC Microtec subsystems thanks to an agreement between the two firms worth SEK 5.6M [1].

Aistech launched its first orbital IOD satellite on December 3, 2018. The Spaceflight Industry's SSO-A SmallSat Express served as the location of the Aistechsat-2 CubeSat. Simultaneously, the SpaceX Falcon 9 rocket hosted the former. The Astrofein PSL performed the CubeSat deployment [139].

By the end of 2018, Aistech contracted Rothschild and Cuatrecasas to perform a Series A funding round among European and American investors. It intended to capture about EUR 25M to help develop the DANU constellation. Besides, Aistech closed a EUR 2M round as a pre-step of the Series A round. It offered investors price advantages compared to the Series A round [29].

Aistech Space introduced its satellite-based air traffic tracking and control system in March 2019. The formalization of their ADS-B product came with a new constellation forecast of 150 Nanosatellites by 2022. They announced these development and expansion moves right before the World Air Traffic Management Congress on April 14 in Madrid. It takes into account the new ICAO regulation, where ADS-B systems will be obligatory in any aircraft [3]. On April 1, Aistech launched the Aistechsat-3 (or DANU Pathfinder) IOD satellite, incorporating the new technology. This 2U CubeSat was on-board the Indian PSLV and was the first Nanosatellite to separate from the rocket's fourth stage [139].

By the end of 2019, Aistech Space reported capital for roughly EUR 24.000 and changed its auditor from UNIAUDIT OLIVER CAMPS to ERNST & YOUNG. Besides, both company founders changed their previous roles to Aistech Space General Managers [125]. Even though they expected to launch the 10 DANU Nanosatellites by mid-2019, the new estimations indicate that it will occur during H1 2020 [136].

6.2 Business Statement and Philosophy

Aistech Space defines itself as a Geospatial Intelligence company. They democratize access to space knowledge, providing valuable information through their captured Earth's surface data to companies, organizations, and administrations. Aistech mission is *"to improve living standards on Earth, helping organizations and companies by providing information about their activities, enabling their decision-making process"*. In the same trend, their vision is *"to become a world reference company providing actionable and valuable information from space"*.

To achieve such mission and vision, Aistech is developing its own Nanosats constellation to gather relevant data anywhere on the planet with high quality and frequency. The combination of this data with other sources, and its processing into highly integrated information will position

Aistech at the forefront of the geospatial intelligence [143, 9].

The company's differential value is the utilization of CubeSats, reducing the building cost per satellite in about 100 times. The increased number of build satellites augments the visit frequency and reduces the data redundancy [214].

6.3 Ownership and Employees

6.3.1 Ownership and Company Structure

Carles Franquesa Giner and Guillermo Valenzuela Ramos established and still own Aistech Space. They both figure as General Managers [172].

Carles Franquesa Giner: Franquesa studied Chemistry, Chemical Engineering, and Industrial Engineering at the U. Autònoma de Barcelona, U. de Barcelona, and the UPC, respectively. Later he earned an MBA at ESADE and a PDG at IESE. Franquesa has 12 years of experience in project, employee, and operative management in industrial companies and consultancies. Besides Aistech, he is a partner at Improva, director at Apertia, and teaches at ESADE [46].

Guillermo Valenzuela Ramos: Valenzuela attended the Universidad Panamericana in Mexico to graduate from Industrial Engineering in the field of Electromechanics. Later on, he obtained an MBA at ESADE. After some years working as an engineer and industrial operations coordinator, he formed part of the foundation of the engineering companies Neuralsens and Skyplanes and the consultancy Secuoya Management [211].

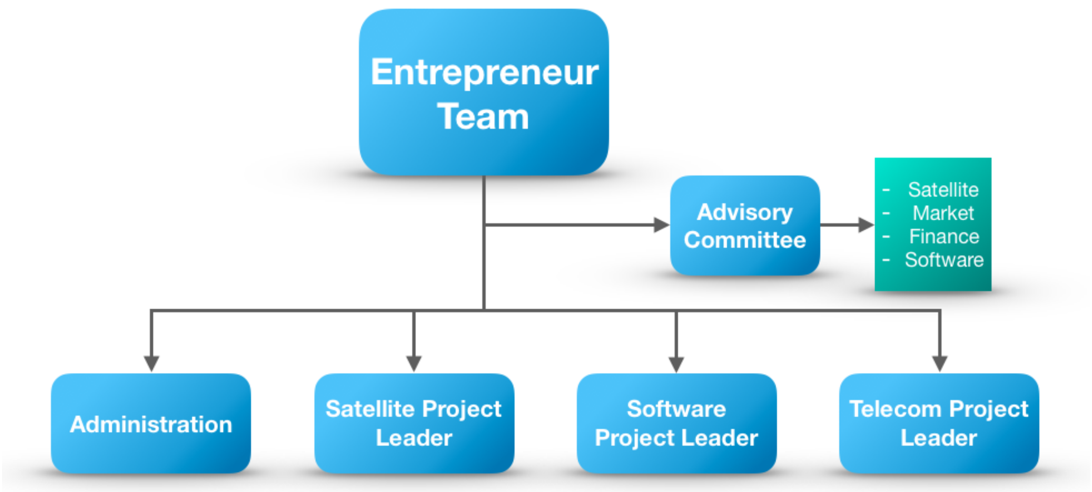


Figure 6.1: Structure of Aistech Space by 2016. *Adapted from: Aistech Space [6].*

An Aistech presentation video revealed the general company structure in 2016. Even though the structure may have changed due to the early developmental stage of the firm at the time, Figure 6.1 presents an adapted version of it [6].

6.3.2 Working environment and Employees

Aistech states that the company develops thanks to the passion of its people. They fly away from routine, leaving space for fresh ideas and people's professional achievements. The projects under development intend to motivate the employees, making it an enjoyable place to work. The company states that they try to create healthy human relationships in their international working environment. They learn from their mistakes to continuously improve [9]. Scarce information on the employees' experience at Aistech is available online. Because the company's web page is who posts these statements, they may be idealized and might not show reality.

The company had its headquarters and main office in Castelldefels (Catalonia) but relocated in 2017 to Nigran (Galicia). In 2017, Aistech opened a subsidiary office for international business in Luxembourg. It is unknown how many employees work at each office or what is their principal purpose, but in 2019 it was estimated that the company had 28 employees [143].

6.4 EO Market Segment and Services

Aistech Space will offer four types of services once the entire constellation of satellites is in orbit. It will be a unique value generator in Aviation Tracking and Surveillance, Remote Asset Management, Earth Observation, and Analytics. Each service contributes to the different marked segments explained below.

The offered services provide increased value to customers thanks to the data-fusion based satellite technology and geospatial intelligence. The information service will be agile, flexible, global, and rigorous, giving a crucial benefit for clients not only in direct custom solutions but also through a positive contribution to society. The services offered can provide specific Earth resources knowledge, helping to guarantee the sustainable development of humanity [9, 143].

Agility: Through an intuitive interface and a robust back-end, the cognitive load reduction during service usage improves the response time to customer requirements change.

Flexibility: The system's flexible nature allows effective adaptation to customer requirements and their needs.

Globality: The Aistech service offers a wide variety of data sources, including thermal data and high spatial resolution, where RAM sensors are available. Moreover, the spatial and temporal coverage is global.

Rigorousness: The information will be accurate and validated. All Aistech sensed data is streamlined, enhanced, and enriched with additional information from external sources.

The following sections present the marked segments and their areas of interest.

6.4.1 Aviation Tracking and Surveillance

All the 150 CubeSats from the Aistech constellation will equip ADS-B payloads. They will collect worldwide aircraft data at any time to know their performance through their position and monitoring data. The Aistech system processes the collected information on-the-ground and provides it to customers for better business intelligence [9].

Air Safety Agencies and Air Traffic Controllers: This data is intended exclusively for aeronautical sector applications. Air Safety Agencies and Air Traffic Controllers can benefit from this Aistech system solution in areas of poor radar coverage. Moreover, aircraft tracking and flight information allow better analysis and optimization of air routes, increasing safety and efficiency.

6.4.2 Remote Asset Management

Aistech Space plans to offer worldwide connectivity for a successful IoT. The service will provide terrestrial and satellite network connectivity to customers, so awareness, monitoring, control, and management over assets are maintained through Machine-to-Machine (M2M) communications. The CubeSats will communicate with ground-based terminals with latencies of less than 15 min thanks to high revisit rates and robustness. This satellite solution has a particular interest in remote areas like oceans or underpopulated terrestrial areas with an infrastructure lack. This service is present in more market segments as it has more extensive applications than the previous one [9].

Agriculture: The agriculture sector can benefit from the interconnectivity of assets that Aistech offers. The main applications are animal tracking, fishery management, yield forecasting, environment, and equipment monitoring.

Mining: The mining sector applications include asset monitoring, exploration optimization, meter readings, and panic alerts.

Construction: The construction sector will benefit thanks to meter readings, employee tracking, health, safety, and security monitoring, logistics, theft prevention, Green energy monitoring, diagnostic tracking, usage tracking, control, and flow monitoring.

Utilities: Among utilities, beneficial applications are the least-cost routing, substation control, monitoring systems, video monitoring, electrical generation, and supply chain monitoring.

6.4.3 Earth Observation

Aistech Space intends to be able to provide EO services. Thanks to the development and implementation of a Multi-Spectral Telescope (MST), the company can offer from near real-time image acquisition to data interpretation and fusion using satellite/aircraft/drone-based platforms. The MST will take images in the visible, near-infrared, and thermal spectral ranges while mounted on each constellation CubeSat. The EO solution has many applications in several market segments [9].

Agriculture: The agriculture sector will benefit from environment monitoring, yield forecasting, and factory monitoring applications.

Mining: This sector applications are exploration, optimization, and environment monitoring.

Fire Management: Data management and information services are its applications.

6.4.4 Analytics

Aistech Space is open to offering innovative solutions in specific on-demand projects based on analytics. Their brand-new full system will combine and integrate data acquired from many sources such as ground sensors, satellites, aircraft, or drones. The applications of this space big data management service are extensive [9].

Precision Agriculture: The agriculture sector could benefit from the focus on extensive crops, large plantations, and the selection of arable areas.

Mining and Natural Resources: This sector applications are the potential locations of minerals, the evolution of open-pit operations, or analysis of farms and forest stands.

Land Monitoring and Critical Zones: Space big data management will be useful for this sector thanks to applications for monitoring the evolution of specific areas, and detecting fire risks, landslides, earth movements, and floods.

Energy Monitoring: This sector includes the monitoring of oil and gas reserves.

6.5 Operations and Satellites

This section will show the past, present, and future Operations of Aistech Space. The satellites used in each operation will be shown, even though the information is scarce.

6.5.1 Aistechsat-1

The Aistechsat-1 was the first Aistech test mission. It consisted of a 6U CubeSat launched on a helium-filled Balloon by Zero2Infinity. This CubeSat aimed to reach 30 km of altitude in order to perform its primary objective of collecting airplane position data through ADS-B signals. Its secondary goal was to test internal systems such as the OBC, the energy, the thermal, and the communications systems. The satellite landing would test its structural resistance [7, 223].

Figure 6.2: Aistechsat-1 during its mission. *Image Credit: Werner [223].*

The firm successfully launched the CubeSat on May 20, 2016. It reached an altitude of 27.95 km, collected the targeted ADS-B data, and could run its systems. A parachute aided the Aistechsat-1 descent for landing, where its structure resisted the impact without a problem. Figure 6.2 presents the CubeSat during the mission. An omnidirectional UHF antenna with four monopoles can be seen for communications. Five solar panels are also visible as well as the cable connection to the balloon [7].

6.5.2 Aistechsat-2

Aistech Space's second mission consisted of an IOD 2U CubeSat, the Aistechsat-2. The data collected and lessons learned during the Aistechsat-1 mission served as its building base. The primary mission objective is to validate the satellite systems and performance in space. The main payloads of the Aistechsat-2 are an AIS M2M communications system and an ADS-B receiver. They obtained crucial data to evaluate the possibility to perform remote asset management and aviation tracking and monitoring. The results will help develop the forthcoming Danu constellation [136, 10].

They launched the satellite on December 3, 2018, on the SmallSat Express Mission (SpaceX) from Spaceflight Industry's SSO-A. The launching vehicle was the Falcon-9 v1.2 (Block 5), starting from the Vandenberg Air Force Base, and the Astrofein PSL/PSL-P was its deployer. This CubeSat is still operative at an orbit of 580 km with an inclination of 97.8° [136, 139].

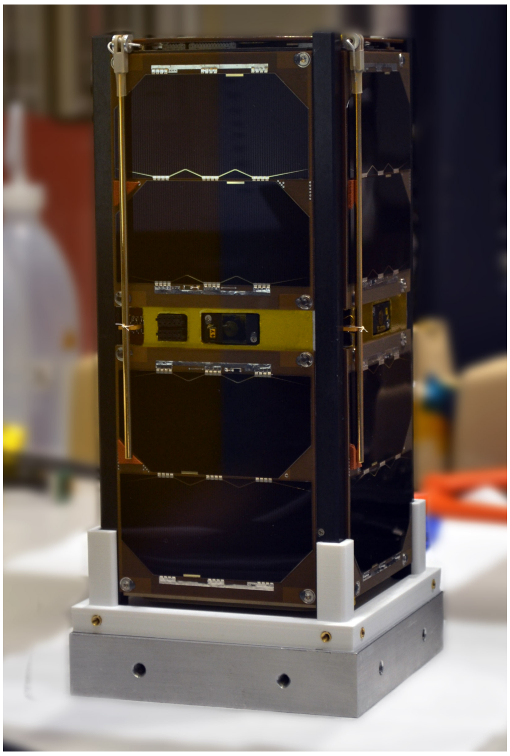


Figure 6.3: Aistechsat-2 at the Aistech Space facilities. *Image Credit: Aistech Space [10].*

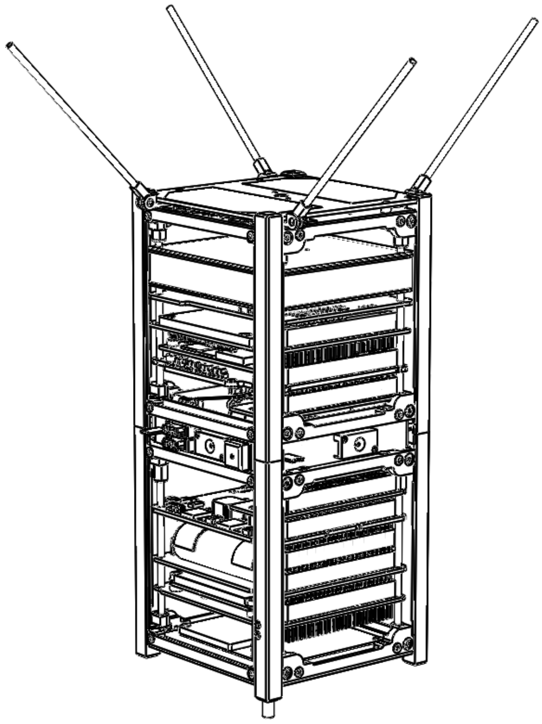


Figure 6.4: Aistechsat-2 internal structure scheme. *Image Credit: Kulu [139].*

Aistech principal contractor for this satellite mission is GomSpace, delivering both platform and payloads. Thus, it uses their CSP protocol on the network layer to transmit packets of data. The Telemetry, Tracking, and Command (TTC) component for data downlink has a frequency of 436.73 MHz and GFSK modulation [114, 160]. Figure 6.3 presents the Aistechsat-2 at the facilities of Aistech Space, while Figure 6.4 shows the internal structure of the satellite. Retracted monopole antennas for communications and solar cells on all the walls can be observed in the former Figure 6.3. The latter Figure 6.4 shows the extended antennas and the different internal PCBs that compose the satellite subsystems and payloads.

6.5.3 Danu Pathfinder

The Danu Pathfinder mission, also known as Aistechsat-3, comprises a single IOD 2U CubeSat. It is an Aistechsat-2 twin satellite, with whom it shares its mission objectives. However, previous data and lessons learned helped to update the subsystems. Its payloads are an AIS M2M communications system and an ADS-B receiver for remote asset management, and aviation tracking and monitoring [136, 10].

Like its twin satellite, GomSpace delivered the Danu Pathfinder, using their communication methods, frequencies and protocols. They launched it onboard the PSLV-QL rocket on April 1, 2019, from the Indian Satish Dhawan Space Centre. The ISIS ISIPOD deployer put the CubeSat on an SSO orbit at 500 km with an inclination of 97.5° [136, 139].

6.5.4 Danu Constellation

The Danu Constellation will be Aistech Space's principal and most prominent satellite constellation with over 100 2U CubeSats similar to the Aistechsat-2 and the Danu Pathfinder. They will incorporate AIS IoT/M2M communications system and ADS-B receiver payloads. The primary mission objective is to collect aircraft and vessel data for aviation tracking and monitoring, and remote asset management worldwide [136, 139, 10].

Aistech expected to launch the first 10 CubeSats by Q3 2019, but a delay occurred until early 2020. GomSpace delivered and performed AIT on the Nanosats, following the contracts signed in 2017 and 2018. The satellites will also equip ÅAC Microtec subsystems [87, 1].

6.5.5 Hydra Constellation

The Hydra Constellation will comprise 30 Aistech 6U CubeSats. The primary objective will be to provide Earth imaging in the thermal, infrared, and visual spectrum. Moreover, the satellites will incorporate AIS IoT/M2M communications system and ADS-B receiver payloads to perform remote asset management, and aviation tracking and monitoring.

The MST payload onboard the Hydra satellites will be used in forest management, agriculture energy consumption, fire, and loss of buildings detection. These CubeSats secondary payloads will be similar to the main Danu constellation payloads to contribute to the Aistech data system. Their power source, like the rest of the Aistech satellites, will be based on solar cells and batteries. GomSpace will build the first 4 CubeSats, which Aistech rescheduled their launching for 2020 after the initial Q4 2019 estimation [137, 10].

6.6 Most important Partnerships

This section will present the most important partners of Aistech Space. The satellite solutions provider GomSpace and their daughter company Aerial & Maritime Ltd have developed strong relations with Aistech regarding platforms and payloads development and data sharing, respectively. Finally, the second part is dedicated to launching companies that have partnered with Aistech.

6.6.1 GomSpace

GomSpace has been Aistech's most important partner. Both firms have taken part in deals and contracts, as shown below.

2016 Order: The company started its cooperation with the delivery of the two first IOD satellite platforms and payloads. A deal worth EUR 200k [114].

2017 Supply Agreement: In September, both companies entered into a 5-years Framework Delivery Agreement for the selling of up to 100 CubeSats to Aistech. It was the subsequent step of a previous MoU and was worth EUR 12.5M [101].

2017 Order: Following the Framework Delivery Agreement, Aistech placed a first 4 CubeSats batch order for the Danu constellation. The company expected GomSpace to deliver the EUR 0.5M order by Q1 2018. It has been delayed [101].

2018 A&M Data Agreement: The spin-off company of GomSpace, Aerial & Maritime Ltd, entered into a 5-years Data Service Agreement with Aistech. Both companies gain access to the other's ADS-B and AIS data in order to improve their service since the beginning. The value of the deal depends on the contract options. A&M's value ranges from EUR 1M to EUR 8M, while Aistech's goes from EUR 1M to EUR 4M [116].

2018 Order: This follow-up order of the Framework Agreement regards six more Danu constellation platforms, making a total of 10. Also, a second part of the order regards the Assembly, Integration, and Verification of the 10 CubeSats, in addition to various engineering services. The order has a value of EUR 1.4M [87].

Future works: It is believed that GomSpace will be the leading partner in the development of Aistech's Hydra constellation. With a smaller constellation than the Danu but larger in satellite size, a framework agreement for the Hydra could be valued similarly to the previous EUR 12.5M [121].

6.6.2 Launching Companies

For each of their technology demonstrator missions, Aistech Space has subcontracted the service of a different launching company. This is a consequence of Aistech not owning the launching stage of their value chain, similarly to Spire Global (see section 5.7 Production System). For future launching service needs, the company may recall a previously-contracted launching provider or subcontract a new one.

Zero2Infinity: The Aistechsat-1 was launched by Zero2Infinity on a high-altitude balloon, reaching 27.95 km. No further collaboration seems probable due to Aistech goal to put their satellites in VLEO orbits [223].

Spaceflight Industry: Aistech launched the Aistechsat-2 onboard the SpaceX rocket Falcon-9 v1.2 Block 5 that was bought by Spaceflight Industry for their SSO-A rideshare mission. The satellite deployer was the PSL/PSL-P from **Astrofein** [136, 139].

ISRO: Aistech launched the Danu Pathfinder through the Indian Space Research Organization and its PSLV-QL rocket. It was deployed using the **ISIS'** ISIPOD [136, 139].

6.7 Financial Status and Risks

This section presents Aistech Space's financial data and risks. Because of the size and private holding status of the company, no insight into its financials or risk management is available. However, it was possible to gather some information in funding announcements, declared capital, and risk analogy with similar companies.

6.7.1 Financial Data

Aistech financials are not public due to the company's private holding status. However, some information regarding announcements of their investment rounds and total money raised in funding was available searching the web, with Table 6.1 presenting it. The two rows highlighted in golden represent the press release recaps that supposedly cover the entire lifetime fundings of the company. However, it is not possible to contrast the information veracity with the known rounds. Aistech announced two planned investment rounds for 2018, but they did not provide any outcome summary. Thus, their execution and final results are unknown.

Table 6.1: Aistech Space investment funding data [11, 142, 223, 4, 5, 161, 144, 214, 29, 23].

Type	Date	Amount (EUR)	Investors	Status
Grant	2015/16/17	35K/10K/5K	BCN Activa	Completed
Loans and Funds	2016	100K	ESA, BCN Activa	Completed
Private Round	2016	300K	Unknown	Completed
Grant	Dec 2016	700K	CINAE, Xunta de Galicia	Completed
Press Release Recap	End of 2016	Over 2M	Over 30 private investors	Unknown
Accelerator/ Incubator	Aug 2017	Unknown	Technoport	Completed
Press Release Recap	2017	3.5M	Inc. 3 Private Rounds	Unknown
Private Round	2018	2M	Pre-step of Series A	Unknown/ Incomplete
Series A	2018	25M	European and American investors	Unknown/ Incomplete
Loan	2019	238K	CDTI	Completed

Observing Table 6.1, the total amount of funds raised by completed private rounds, loans, and grants is EUR 1.4M. If the press release recaps were valid, it would rise to EUR 3.74M. Finally, if the investment rounds with incomplete status turn out as expected, the total funds would rise to EUR 30.7M.

According to the Commissioned Research that the Danske Bank executed over GomSpace in December 2019, Aistech Space should consider and equity raise. The authors state that Aistech needs to fulfill its commitments to GomSpace, and the company should strengthen its financial situation to do so.The fact that the Danu constellation launches were delayed could be a consequence of a lack of funding [121].

Aistech Space capital is publicly available at the *BOLETÍN OFICIAL DEL REGISTRO MERCANTIL*, initially from Barcelona and later from Pontevedra. Over the years, the capital has increased from the starting quantity slightly higher than EUR 3K, as the company is an "Ltd" (*"SL" - Sociedad Limitada*). Table 6.2 presents the registered capital at the end of each Aistech's life year and the moment of its establishment [125].

Table 6.2: Aistech Space registered capital [125].

Year	Amount (EUR)
July 30th, 2015	3,006.00
End of 2015	10,006.00
End of 2016	20,971.30
End of 2017	22,920.41
End of 2018	23,415.84
End of 2019	24,366.74

6.7.2 Aistech Space Risks

Due to the nature of the company, Aistech Space presents similar risks to Spire Global. As both companies have private holdings, their risk mitigation techniques are not public. The most relevant financial risks are presented below [107].

Credit Risk: Risk regarding a third party not meeting its financial obligations under a contract and leading to a financial loss. Aistech will be vulnerable to this risk if its customers lack financial resources or other circumstances beyond Aistech control occur. Up to date, any Aistech client has been made public.

Interest Risk: It appears when the company takes a loan. It exists for the company as Aistech has reportedly taken various loans to increase the capital. Proper monitoring of the interests may limit the effects of the risk.

Foreign Currency Exchange Risk: Risk present when the company operates globally. The current situation of Aistech shows that their core operations are in EUR, leaving this risk almost negligible. However, the will to involve American investors may increase US operations in USD, resulting in a higher foreign currency exchange risk.

Liquidity Risk: It regards the company's lack of funding and sufficient financial liquidity to meet short term financial demands. This risk seems high for Aistech, as delays in satellite launches happened due to a lack of financial resources. The company should improve its funding management and monitoring, together with the maintenance of cash assets.

In addition to those financial risks, Aistech Space can also be defenseless to other jeopardies that would affect the company's business, financial position, and future results. The most substantial risks are presented bellow [107, 205].

Execution Risk: As Aistech plans to increase its production to achieve a 150 satellite constellation by 2022, this risk comes inherent with an underperformance possibility. However, it is early to predict the impact of this risk.

Launching Risk: Because Aistech does not own this element in the value chain, the company is vulnerable to launching firms when putting satellites in orbit. Costs, availability, and failures could negatively affect Aistech plans and bring economic repercussions.

Market Competition Risk: Aistech is a small company inside the small satellites sector because of its early development stage. Competitors with higher market share are developing new technologies and products. If cutting edge solutions are not implemented, a loss of offers and maker share could occur. The rising demand for LEO based services has increased the number of competitors, resulting in higher price and quality competitions.

New and Emerging Market Risks: New competition from other developed sectors could threaten the Smallsats market. The value proposition and technology development of such sectors, like large satellites, terrestrial, and airborne platforms, could stagnate or even eliminate the Smallsats market.

Customers Risk: Not having enough customers is a real risk for Aistech, as it seems to be the case right now. Unpayments could lead to financial instabilities. That may be another reason why the delays of satellite launches have occurred.

Product Quality Risk: If the development of a product goes wrong or services do not have enough quality, Aistech will not meet market expectations. Thus, customers would lose trust in the company, bring an adverse impact. Aistech should always seek quality in its products and services, even when resources are limited.

Essential Personnel Risk: Skilled personnel is essential for a high-tech company like Aistech Space. They should be retained or replaced adequately to avoid interruptions of ongoing projects and development plans.

(This page was intentionally left in blank.)

7 | Business Model Analysis of the Case Studies

This chapter will present the Business Model Canvas (BMC) and its application to the three Case Studies presented before. The first section will explain the methodology, while the following three will address each company's Case Study.

7.1 Business Model Canvas (BMC)

Osterwalder [157] developed the BMC as a tool or *shared language to describe, assess, and improve a business model.* Thus, a business model is something that *describes the rationale of how an organization creates, delivers, and captures value.* The proposed BMC presents the complexities of how enterprises function in a simple, relevant, and understandable way. It is composed of nine basic building blocks divided into the left and right sides of the BMC. The former is related to the company's internal efficiency while the latter is to the external value. Figure 7.1 shows their distribution in the canvas and the two-sides division. The building blocks cover the four principal business areas; customers, offering, infrastructure, and finances [157].

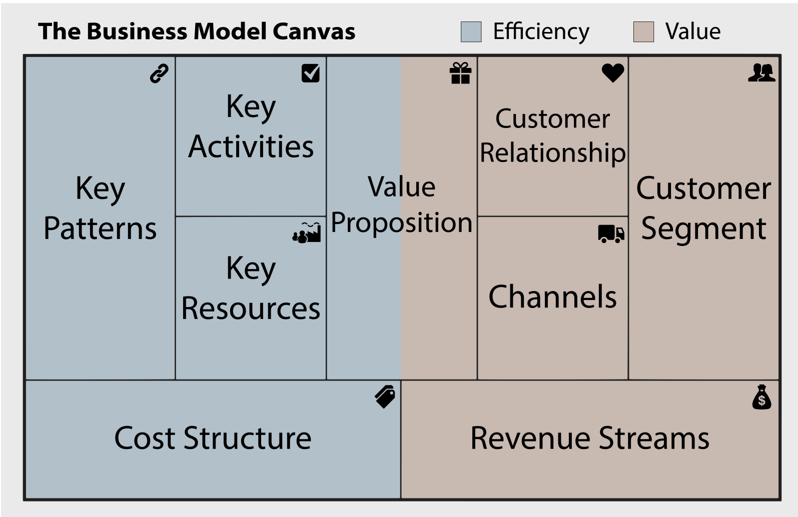


Figure 7.1: Business Model Canvas building blocks and two-sides division.

Customers:

***Customer Segment*:** Comprises the clients that the company aims to reach and serve, and are grouped in segments based on their common needs, behaviors, or attributes.

***Channels*:** Describes the way the company communicates and reaches the Customer Segments to provide their Value Proposition. The Channels have five different phases; awareness, evaluation, purchase, delivery, and after-sales.

***Customer Relationship*:** Describes the established relationships with the Customer

Segments. Customer acquisition, retention, or boosting sales drive the relationships, going from personal to automated.

Offering:

Value Proposition: They are products and services offered that create value for the Customer Segments. They can be innovative or similar to market competitors', bringing added features or attributes.

Infrastructure:

Key Resources: They are the most valuable assets that make the business model work. These resources can be physical, financial, intellectual, or human.

Key Activities: They are the company's most important actions to make its business model work, categorized in production, problem-solving, or platform/network.

Key Partnerships: The network of suppliers and partners needed to make the business model work. It helps to optimize business models, reduce risk, or acquire resources.

Finances:

Revenue Streams: They are the cash inflows a company generates from its Customer Segments' onetime or ongoing periodic payments. Pricing can vary from fixed list prices, bargaining, auctioning, or market/volume dependent.

Cost Structure: It refers to all the costs involved in the operation of a business model. Companies can have cost-driven or value-driven structures. Costs can be fixed or variable, with companies' economies being of scale or scope.

7.2 BMC of Spire Global

The data from Spire Global Case Study generated its BMC shown in Figure 7.2. Each topic is enclosed in a Post-it note, stuck inside its building block. The notes have color dot stickers to represent to which value proposition product they relate. The colors are **Blue for Sense**, **Red for AirSafe**, **Green for Stratos**, and **Orange for the Orbital Services**. Topics can have from one sticker to all four stickers. All the four Sense, AirSafe, Stratos, and the Orbital Services are fully operational. The description of each building block composition is below.

***Customer Segment*:** Spire offers its products to five customer segments. The company has a **Diversified** customer segment, using its value chain elements to develop its constellation and to co-create satellites with clients. Each type of sensed data has a distinct segment in a **Niche Market**, but the *Supply Chain and Logistics* can create value from every kind. The *Government and Military* segment benefits from all Spire's sensed data and its capacity to develop customized EO satellites.

***Channels*:** The firm creates **Awareness** of itself through *Social Media* and its *Web Page*. The latter can be used to contact the *Sales Team* and **Purchase** the products. Data products are **Delivered** through the *Online API Platform* while the customized satellite delivery communications and **After Sales** go through the *Internet* and *Telephone*.

***Customer Relationship*:** Customers can purchase products' data packages straight from Spire's web page in a **Self-Service** way. However, **Personal Assistance** occurs as an after-sales support relationship. This type of contact also happens when the firm **Co-creates** satellites with customers. Spire offers free tryouts of its API so engineers can test the data and its adaptability to their systems.

Value Proposition: This block shows Spire's four main products for space-based data collection and customizable co-creation of sensing satellites. The Lemur-2 constellation, with over 100 CubeSats, allows high revisit times and global coverage. Together with the analytics platform, they convert Spire's *Data Products* into reliable value-added services. The company's robust infrastructure enhances the *Orbital Services* product through flexibility and fast deliveries. The **Newness**, **Design**, and **Accessibility** of all the products contribute to customer value creation, while **Customization** is a significant element in the *Orbital Services*.

Key Resources: Spire Relies heavily on its **Physical** and **Human** resources. Its facilities, ground station network, satellite constellation, API, and data analytics platforms are the physical core of its business value chain. Engineers play another vital role in the company, developing high-tech CubeSats and the platforms. The firm takes care of them with its philosophy, where the employee's personal development is a priority.

Key Activities: The firm controls all the elements of its value chain except one. These activities relate to **Production**, allowing Spire to build satellites faster, control the downlinked data, and deliver it faster to customers. The constant satellite development using COTS components allows continuous updates of the Lemur-2 constellation.

Key Partnerships: Spire partnerships with Ground Station and Launching companies have motivation in the **Optimization and economy of scale**, performing activities that reduce the firm's costs. The other partnerships are motivated by a **Reduction of risk and uncertainty**, with most of them aiming to develop new product applications or resell them in new regions.

Revenue Streams: The company generates revenues in two ways; the **Asset Sales** of customized satellites and the **Subscription Fees** for data product plans. The former has dynamic pricing, subject to contract negotiation, while the latter presents fixed prices. These prices depend on the product and the features it provides.

Cost Structure: Spire Global is a **cost-driven** company. It brings low-price COTS components to space, generating accessible global EO data. The fixed costs of facilities, salaries, and maintenances dominate the variables.

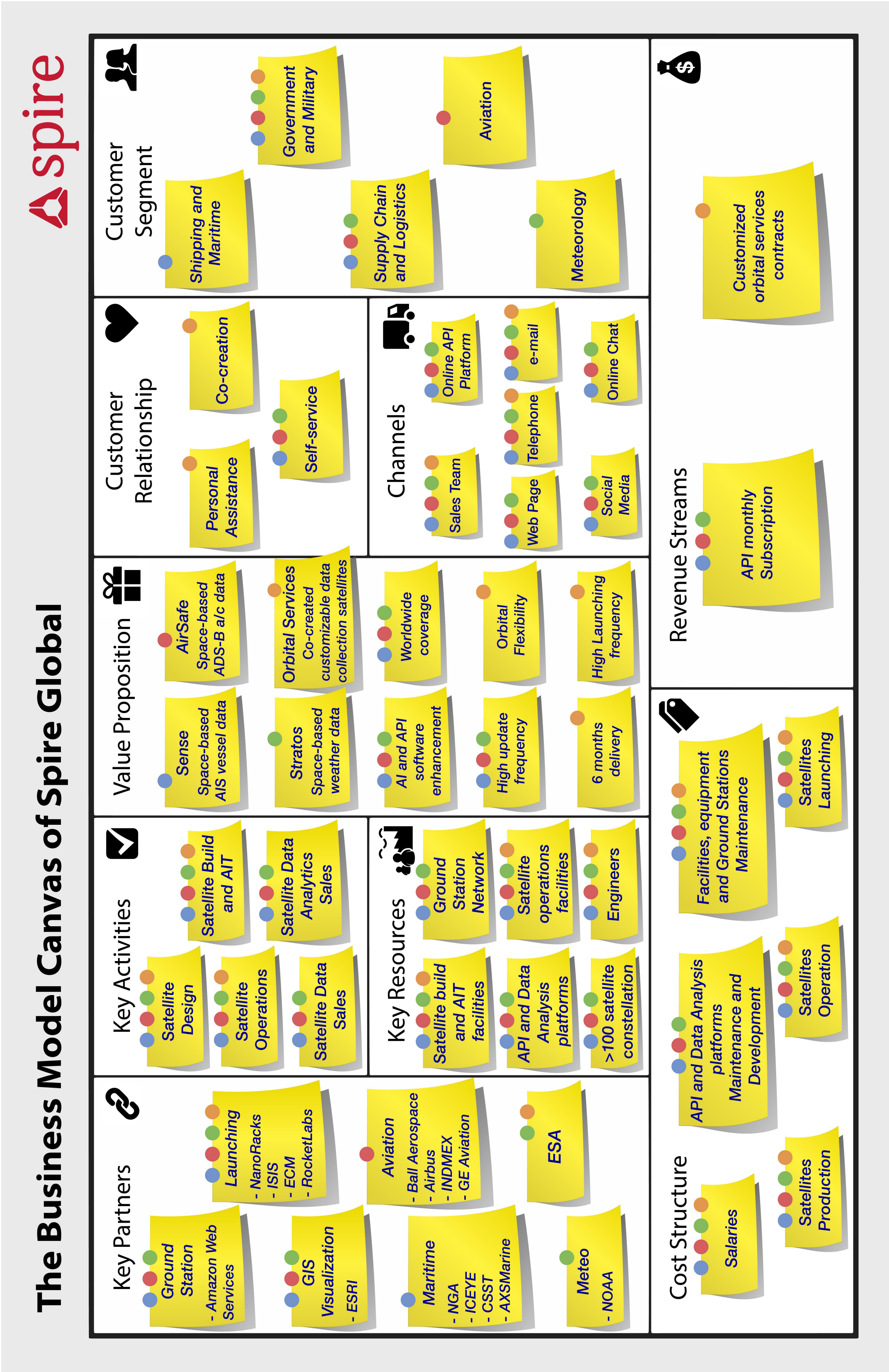


Figure 7.2: Spire Global Business Model Canvas.

7.3 BMC of GomSpace

The Case Study that analyzed the GomSpace Group based its BMC from Figure 7.3. Similar to Figure 7.2, the Post-it notes exhibit topics of the building blocks. The color dot stickers code represents to which value proposition product a topic is related; **Blue for Payloads**, **Red for Subsystems**, **Green for Satellite Platforms**, **Orange for the Additional Services**, and **Purple for Constellation Management**. Each topic can have from one to all five stickers. The only product that is still not fully operational is the Constellation Management. Hence, the GomSpace BMC could still change once it is established. The description of each building block composition is below.

***Customer Segment*:** GomSpace knows it has four **Diversified** customer segments. The most important is the *commercial*, involving companies that aim to get profitability from applications based on GomSpace value propositions. Those companies are in **Niche Markets** strongly related to Telecommunications and EO. All the customer segments are interested in the totality of the company's value proposition.

***Channels*:** The Group uses *Social Media* and its *Web Page* to create **Awareness**. In order to **Purchase** a product, a client should contact the *Sales Team* through the *Customer Portal*, while the **After Sales** and support occur through the *Help Center*, *e-mail*, and *Telephone*. The product delivery adapts to each particular case.

***Customer Relationship*:** Clients get **Personal Assistance** when they contact the company to acquire a product. Moreover, full-service satellite solutions require **Co-creation** under contracts to satisfy client necessities.

Value Proposition: GomSpace offers its *Payloads*, *Subsystems*, and *Satellite Platforms* separately. The Group also offers *Additional Services* like ground station support, launch services, or payloads and subsystem integration. The company aims to offer mainly its *Satellite Solution* product, integrating the rest of the products to provide a full service. **Newness**, **Design**, and **Accessibility** of all the products contribute to customer value creation, while **Customization** is essential for the *Satellite Solution*. The *Constellation Management* will be operative soon.

Key Resources: The Group relies on **Physical**, **Intellectual**, and **Human** resources. Its *Facilities* for Satellite Production and Constellation Management form the business's physical core, whereas *Engineers* form the human. The Intellectual resources are *CubeSats, Modularization Technology*, and the *RF and GOMX Project experiences.* These resources play a crucial role in GomSpace's success.

Key Activities: GomSpace has its key activities related to **Production**. The *Reduction in Development Time* comes from the usage of COTS components, distributed architectures, parameter systems, on-orbit reprogramming and calibration, and in-the-loop testing. It allows the firm to deliver more products in tighter schedules.

Key Partnerships: The company's *IOD* and *Spin-off* partnerships follow a **Reduction of risk and uncertainty** motivation. They share the risk and assist each other in technology development and new business opportunities. Large Constellation clients follow an **Optimization and economy of scale** motivation. These customers are considered partners due to their cooperation, where GomSpace gains experience, develops new technologies, and learns from the process.

Revenue Streams: The company generates revenues through **Asset Sales** of components and satellite solutions contracts, and **Usage Fees** of additional services and constellation management. Components and some services may have fixed prices, depending on the purchase volume, while satellite solutions and other services are subject to negotiation of contracts.

Cost Structure: GomSpace is a **cost-driven** company that uses its RF experience and low-price COTS components to create a more accessible space. The fixed costs of facilities, salaries, and maintenances overshadow the variables.

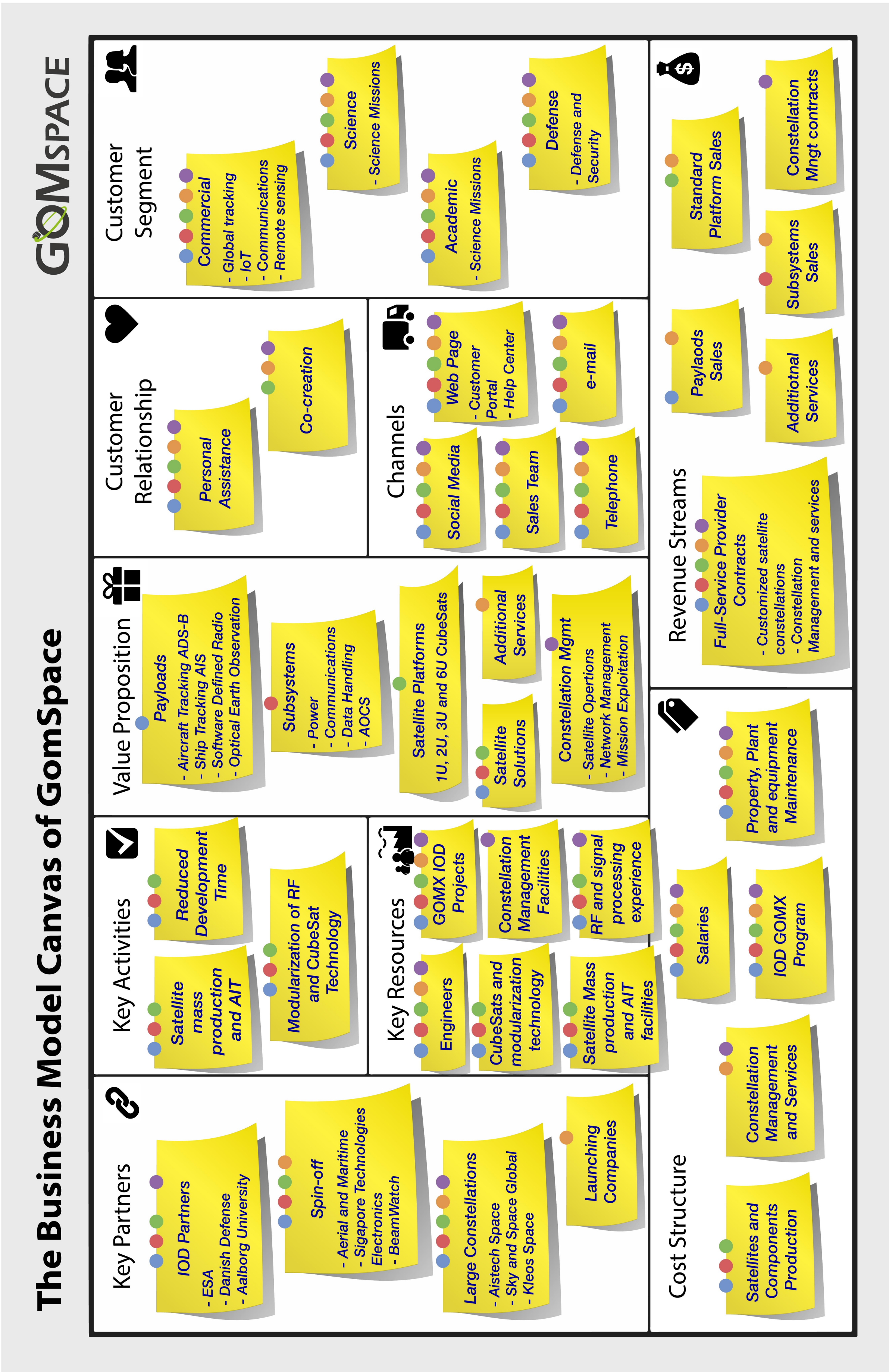


Figure 7.3: GomSpace Business Model Canvas.

7.4 BMC of Aistech

Aistech Space's Case Study gathered useful information for its BMC in Figure 7.4. The Post-it model follows the previous BMCs. The color dot stickers representing the value proposition products are **Blue for Remote Asset Management**, **Red for Aviation Tracking and Surveillance**, **Green for Earth Observation**, and **Orange for On-demand Analytics Projects**. Topics can have from one to all four stickers. Aistech does not have all the satellites of its two constellations orbiting. Only two CubeSats capable of AIS and ADS-B are in space. Thus, the BMC information presented in Figure 7.4 may vary once the 100 2U CubeSat (Danu) and the 30 6U CubeSat (Hydra) constellations are operational. The description of each building block composition is below.

***Customer Segment*:** Aistech products can generate value in multiple customer segments. This **Diversification** of the customer segment comes from the company's value generated by the space-sensed data and the analytics platform.

***Channels*:** The company creates **Awareness** through *Social Media* and its *Web Page*. **Purchases** would occur contacting the *Sales Team*, but it is not clear how or when will it be available. It is possible to contact Aistech for support through *e-mail*, *Telephone*, or *Online Chat*.

***Customer Relationship*:** The company's early development stage suggests that customers would get **Personal Assistance** through the processes in the Channels block. Besides, Aistech will practice **Co-creation** in its on-demand product.

Value Proposition: Both constellations that Aistech is developing have AIS and ADS-B payloads, while only the Hydra CubeSats will add an MST. The firm will sell the data collected in value-adding services through the Internet. Furthermore, Aistech is developing an analytics platform to process data from internal and external sources. The company wants to generate more profit by selling this product separately. These propositions will bring **Newness**, **Design**, **Accessibility** to space at lower **prices** than competitors.

Key Resources: Aistech Space relies heavily on **Physical** resources; the two future constellations, its facilities, and the data analytics platform. They form the core of the company and are fundamental for its prosperity. The firm has its **Human** resources in qualified engineers.

Key Activities: The company focuses on the development of its **Platforms**, including the satellite constellations and data analytics platform. Their continuous update and development are crucial to perform the actions that will generate the value proposition.

Key Partnerships: The firm partnerships with the *launching companies* and with *GomSpace* for the satellite's development, comes from the **Optimization and economy of scale** motivation. Aistech contracts them to perform activities that reduce costs. The *Start-up Incubators*, the *CINAE*, and *A&M* partnerships respond to the **Reduction of risk and uncertainty** motivation.

Revenue Streams: It is believed that each of the four products will generate revenues through **Subscription Fee**, even though the Analytics Projects may have **Usage Fees**. They most likely will have fixed prices dependent on the products and the features it provides.

Cost Structure: The company is **cost-driven**, making space accessible to everybody with low-price COTS components. The fixed costs comprise the facilities, salaries, and maintenances, while the variables are for launchings and satellite production, including the contracts with GomSpace.

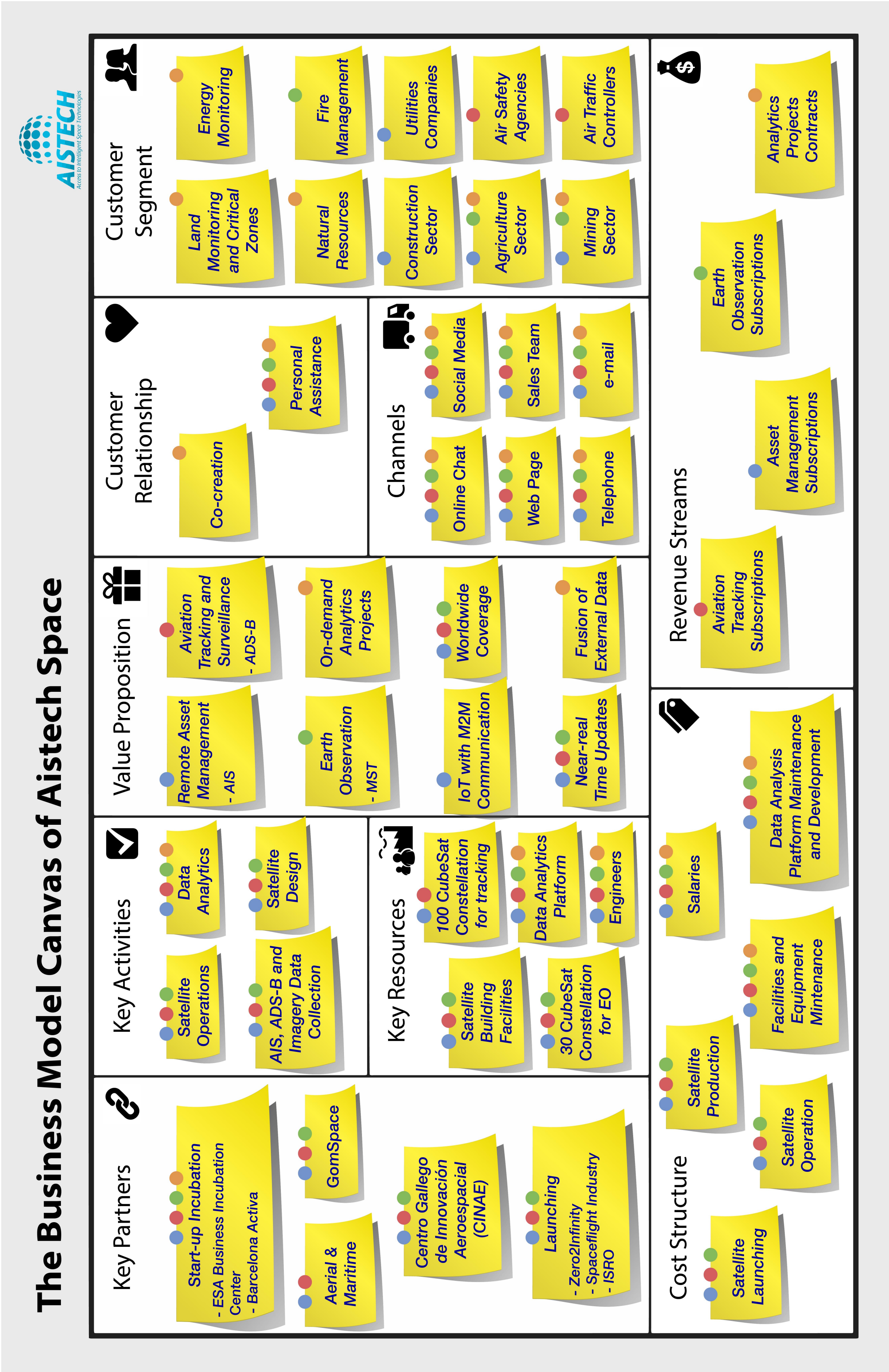


Figure 7.4: Aistech Space Business Model Canvas.

8 | Business Model Patterns and Success Factors

The three analyzed NewSpace companies showed diverse objectives and development stages, with their BMCs highlighting similarities and differences. Spire Global principal value propositions deliver near-real-time data from space to organizations associated with aviation, maritime, and weather tracking. Its constellation of over 100 CubeSats allows its products to be fully operational. Aistech Space aims similar goals, but instead of weather, it focuses on EO imagery. Its development stage is less advanced than Spire's, with only 2 IOD satellites orbiting. The GomSpace Group targets another niche in the market, developing and commercializing Nanosat COTS payloads and platforms for space-based businesses. The Group development stage is advanced, being capable of providing full satellite constellation solutions for IoT, communications, tracking, surveillance, and remote sensing. This chapter will try to identify the five Business Model Patterns described by Osterwalder [157] in each company's business model. A sixth Pattern proposed by the UPC student Canyelles Pascual [21] in her TFG, identifies companies trying to democratize an industry. This "*Democratising*" Pattern will also be taken into consideration for the companies' evaluation.

8.1 Business Model Patterns Description

The first step to identify the Patterns in each company is to understand them. When business models have similar characteristics, BMC building blocks, or behaviors, they are following a Business Model Pattern. Table 8.1 presents a summary of the core Patterns defined by Osterwalder [157] and their subdivisions. A company business model can follow one, more, or none, leaving room for new Patterns to emerge based on other business concepts [157]. Table 8.1 also indicates in which company the Pattern is identified through their logos; Spire Global (), GomSpace (), and Aistech Space ().

The first Pattern in Table 8.1, the Unbundling Business Model, is based on the fact that there are three types of businesses, focusing on products, customers, or infrastructures. Even though these Patterns can co-exist in a company, they should be in separate entities as they have cultural, economic, and competitive differences that may lead to conflicts or undesirable trade-offs [157]. The three types are described in Table 8.1.

Table 8.1: Business Model Patterns and their identification in the companies [157, 21].

Pattern	Description		Applies
Unbundling Business Models	Product Innovation	A firm aims early market entry to charge premium prices and get a significant market share. It fights for talent and focuses on employees and product development.	
	Customer Relationship Management	A firm aims to gain large wallet share through high cost for customer acquisition and economies of scope. It seeks rapid consolidation and is deeply service-oriented, with a customer-comes-first mentality.	
	Infrastructure Management	A firm aims low unit costs and economies of scale through large volumes. It seeks rapid consolidation, standardization, predictability, and efficiency while focusing on high fixed costs and delivering infrastructure services.	
The Long Tail	A company sells less of more, offering a large number of niche products that sell infrequently but can be as lucrative as bestsellers in traditional models. It requires low inventory costs and reliable platforms to have niche content always available.		-
Multi-Sided Platforms	A Platform that brings together distinct but interdependent customer groups. It creates value to a group only if the others exist, facilitating their interactions. The market grows in value through growth in number, the network effect.		-
FREE as a Business Model	At least one customer segment benefits continuously from a free-of-charge offer. Other segments, or parts of the model, finance the non-paying customers. It can use advertising as a Multi-Sided Platform, a Freemium, or a Bait & Hook strategies.		-
Open Business Models	A company systematically collaborates with outside partners to create and capture value. It can be "*outside-in*," exploiting external ideas within the firm, or "*inside-out*," providing external parties with ideas or assets not used internally.		
Democratizing Business Models	A company tries to make a market accessible to as many commercial customers as possible, focusing on price, utility, and practicality. Low variable costs lower the price with automated channels, IT, and standardization. New value propositions are achieved, developing Value-Added Services with user-friendly interfaces, clarity, and conciseness. Partnerships are crucial to strengthening the brand reputation and perform key activities.		

8.2 Spire Global Patterns

Spire Global business model has been identified to follow three Patterns exposed in Table 8.1; the Unbundling Business Model focused on Infrastructure Management, the Open Business Model, and the Democratizing Business Model. Spire's Case Study and BMC served to identify those Patterns and discard the rest. The company does not have a strong focus on its customers and, even if it invests in talented people and product development, the firm concentrates on its satellite constellation and platform. Spire targets some niche market customer segments, but it only offers four main products. Those customer segments do not get any product for free and are independent of each other, constituting separate markets.

The principal goal of the **Unbundling Business Model** focused on **Infrastructure Management** is to lower the high fixed costs through high volumes production of low-cost units. Spire controls the entire manufacturing of its satellite constellation with over 100 units. The large numbers of CubeSats help the company capture more data worldwide with a better temporal resolution, meaning that they are not used only to lower costs. Besides, the firm applies VIS, managing its entire value chain elements except for the satellite launch. Hence, its investments in infrastructure to develop the CubeSats, acquire, and process the space data represent a large part of the company's high fixed costs. I.e., the significant initial investment in developing Spire' long-lead hardware brought dramatic cost savings, the benefit of owning the embedded firmware, and the flexibility in the supply chain. Spire mitigates costs with standards, predictable designs, and efficient methods (see section 4.5 Production System). Spire Global uses its CubeSat constellation and analytics platform to deliver a data infrastructure service (Sense, AirSafe, and Stratos) to business customers (B2B).

Spire's non-data value proposition product may follow a distinct Pattern inside the company. The "*outside-in*" **Open Business Model** Pattern was identified in Spire. To standardize and reduce design costs, the company uses COTS components in its satellites. The firm usually buys parts with low lead from external parties in the consumer electronics industry. Hence, Spire can reduce time and effort by exploiting external ideas within the firm.

The "*inside-out*" version of the Pattern is characterized by a company providing its unused ideas or assets to external parties. The firm offers co-created, customizable data collection satellites to customers based on Spire's strong value chain. It may develop new technologies for satellite remote sensing that are not useful for its core value propositions. Thus, these platforms could incorporate them, letting secondary market customers take advantage. Other examples are Spire's partnerships to develop new applications of their collected data in the maritime, aviation, and weather sector. Depending on the results, they could be "*inside-out*" or "*outside-in.*"

The last observed Pattern in Spire Global is the **Democratizing Business Model**, which adjusts the best to the company. Since its creation, Spire has aimed to facilitate access to space. With that in mind, the company developed a disruptive technology to create satellites that sense data from space. Canyelles Pascual [21] underlines in her TFG some common aspects in business models trying to democratize a product like Spire.

Open the market to everyone: Spire has targeted new customers in the maritime, aviation, and meteorological sectors that could not know they needed data from space. I.e., Maritime transport data to analyze has increased exponentially. The combination of data from space and a powerful AI platform can provide new insights. Spire will continue to increase its customers with new features of its satellites and analytics platform.

Lowering the price and adding value to the services: The company cost-efficiently senses data from space, which used to be a task for expensive satellites or terrestrial systems. The Constant New Product Introduction model for building CubeSats allows dramatic reductions in costs and building cycle time. The firm's infrastructure ensures a rapid transmission of the downlinked data to the cloud analytics platform. It processes information to deliver Spire's data services at low prices, enabling better accessibility, and adding value in speed and reliability. I.e., Stratos can provide reliable weather forecasts at reasonable prices outside Europe and the US, where they are already good. The data analysis investment provides customer-friendly experiences, like in the ESRI platform. Moreover, the co-create remote sensing CubeSats are various orders of magnitude cheaper than traditional EO satellites.

Automated channels and customer relationships: Spire uses a data cloud system to downlink data from satellites, process, and deliver it. Customers can acquire Sense, the most established product, automatically through the web page. The other products still require online contact with the sales team but will follow Sense's methods once they are in further developmental stages. Spire delivers its product data automatically through the company's API. Most of the company-customer interactions are through the Internet.

Have a large number of partnerships: Agreements with other organizations should help a company strengthen its brand, develop critical activities, or provide key resources. Spire has partnered with launching companies to cover its only not-owned value chain element. In a movement to reduce the ground station network ownership, the company partnered with Amazon Web Services. Spire has been involved with multiple platforms to develop new technologies in diverse fields and to strengthen its brand. They include aerospace leaders like Airbus, ESA, or GE Aviation.

Reducing variable costs: Spire has reduced variable costs by integrating IT platforms, using COTS components, CubeSats, and predictable designs, and standardizing methodologies. The implemented actions under the Constant New Product Introduction model for manufacturing have dramatically reduced materials and conversion costs (see section 4.5 Production System). Automation has been vital in many processes like test documentation, and data acquisition, downlink, analysis, or delivery.

The **Democratizing Business Model Pattern** integrates the main characters of Spire's other two Patterns. "*Lowering the price*" and "*Reducing the variable costs*" comprise the company's Infrastructure Management principal aspects. Spire uses standards, predictable designs, and efficient methods to produce CubeSats in high volume at low unit cost, and made significant investments on infrastructure to switch costs to fix, increase productivity and control all the procedures. The customized Orbital Services product from the "*inside-out*" version of the Open Business model fits the "*Adding value to the services*" aspect of Democratizing. It is an inherent characteristic of this value proposition. On the other hand, the Open Pattern's remaining partnership relations are covered under the "*Have a large number of partnerships*" feature of Canyelles Pascual's Business Model Pattern.

8.3 GomSpace Patterns

The business model Patterns identified in GomSpace are the Unbundling Business Model focused on Product Innovation and Infrastructure Management, the Open Business Model, and the Democratizing Business Model. The other Patterns were discarded for various reasons. GomSpace does not have a strong focus on its customers, even though it provides customized satellite solutions and additional services. The Group offers many products, but they are all directed to the CubeSats niche market. Its customer segments are independent of each other, and none gets any free product.

Since its establishment, the GomSpace Group centered on the development of its products, following a **Product Innovation Unbundling Business Model**. It aimed to develop Nanosatellite subsystems based on its expertise in advanced radio technology. GomSpace rapidly gained a large Nanosats market share with international recognition and kept growing by hiring talented engineers. Its product portfolio developed with new subsystems and satellite adjacent services. However, GomSpace products, and the Nanosat market, are characterized by using cost-efficient COTS components, keeping product prices relatively low.

Its Initial Public Offering provided GomSpace additional capital to strengthen its position in the Nanosats sector. Since then, the company has enlarged its facilities to ramp-up productions into high-volumes. The Group has also increased modularization and production automation to support this transition. Thus, GomSpace is shifting into an **Infrastructure Management Unbundling Business Model**, lowering costs through high volumes production of low unit costs. The company's Lean Manufacturing methods to Reduce Development Time (see section 5.7 Production System) are examples of how GomSpace produces CubeSats. However, most of the firm's value propositions are not infrastructure services but physical products.

The third Pattern observed in GomSpace is the **Open Business Model**. The Group uses COTS components from external parties in an "*outside-in*" version of the Pattern. It also develops many new technologies in IOD missions with partners such as ESA, the Danish Defense, or the Aalborg University, getting their technologies, assets, or facilities. The "*inside-out*" version of the Pattern could also be identified as the firm sells its ideas and technologies to companies with spin-off relationships. For example, the spin-out company A&M will base its 3U CubeSat constellation entirely on GomSpace technology, tracking aviation and maritime traffic near the equator (see sections 5.8.3.2 and 5.9.2.1 Aerial & Maritime Ltd (A&M)).

Finally, the **Democratizing Business Model** adjusts the best to GomSpace, who tries to democratize the Nanosats technology among commercial space customers requiring radio-based surveillance and communications solutions. The Group goes one step forward regarding companies like Spire Global or Aistech Space, as it understood their satellite solutions requirement. GomSpace offers all the services related to Nanosats, persuading these companies to use them. The same common aspects than in Spire Global are analyzed for this Pattern [21].

Open the market to everyone: GomSpace focuses on commercial companies that need satellite platforms to offer their value proposition. Hence, it can provide any service related to Nanosatellites, trying to convince customers that Nanosats are their best satellite solution. Significant investments in product development and engineers are a constant in GomSpace methods, rewarding it with a sizeable market share.

Lowering the price and adding value to the services: The products offered have low prices due to their modularization, standardization, high production volumes, and Lean Manufacturing methods (see section 5.7 Production System). Moreover, CubeSats technology is many orders of magnitude cheaper than traditional satellites. The customization a client can get in some products adds significant value to the services, as in the satellite solutions, the additional services, and the constellation management. Besides, the continuous investment in product development and qualified engineers aims to get value propositions with increasing added value.

Automated channels and customer relationships: GomSpace has implemented a powerful web page to communicate with clients. It incorporates a customer portal and a help center to aid them. However, the core communications are with sales teams, and the delivery channels are physical since the company's main products are customized material objects. The constellation management value proposition will most likely be a more automated product with Internet-based communications and data delivery.

Have a large number of partnerships: The Group has developed many partnerships to strengthen its brand, develop essential activities, or obtain critical resources. GomSpace has entered into agreements to develop numerous technologies, as with ESA for the constellation management MCOP project. It has deals to perform its additional service value proposition, like with launching businesses. Furthermore, the firm has three spin-out partnerships for activities in new untouched domains. The case of A&M, whose 3U CubeSat constellation will be based entirely on GomSpace technology, tracks aviation and maritime traffic near the equator. The Group clients of large constellation projects are also partners because the company gains experience and develops new technologies from the collaborations.

Reducing variable costs: GomSpace reduces costs by using COTS components, CubeSats, predictable designs, standard methodologies, and high volume production. Lean Manufacturing methods, based on reducing the development time (see section 5.7 Production System), increase productivity, and minimize waste in the production process.

The GomSpace Group Pattern of a Democratizing Business Model covers the most distinctive aspects of its others. Investments in product development and engineering personnel, and the increase of the offered portfolio from the Product Innovation Pattern are included in the "*Adding value to the services*" feature. The large market share targeted in this Pattern responds to the desire to "*Open the market to everyone.*" Similar to Spire, the principal Infrastructure Management characteristics of Lean Manufacturing, facilities investments, high fixed costs, and high production volumes can be comprised under the "*Lowering the price*" and "*Reducing the variable costs*" aspects. Finally, GomSpace multiple Open Pattern collaborations follow a trend to "*Have a large number of partnerships*" and to "*Add value to the services.*" Therefore, this NewSpace company fits the **Democratizing Business Model Pattern** with a great analogy.

8.4 Aistech Space Patterns

There were three Business Model Patterns identified in Aistech Space; the Unbundling Business Model focused on Customer Relationship Management, the Open Business Model, and the Democratizing Business Model. The rest were discarded for diverse reasons. Even though Aistech invests in developing its value proposition and infrastructures, they are not its core investment. The company does not manufacture its satellites. It buys them and centers in developing a service-oriented platform to analyze data and deliver it to customers. The firm aims niche market customer segments, but it has only four offered products. Those customers are independent of each other, constitute separate markets, and none get any free product.

Aistech will most likely concentrate on developing its wallet share and an economy of scope. Thus, the **Unbundling Business Model** focused on **Customer Relationship Management** was identified. The company centers on developing a cloud-based analytics platform that provides highly service-oriented data products. Aistech is acquiring the Danu and Hydra constellations of 100 and 30 CubeSats from GomSpace to capture Earth's surface data for companies, organizations, and administrations. The data products and analytics platform value propositions will be added-value services intended to many customer segments in a large wallet share. Aistech will also concentrate efforts on the data sales and distribution.

The firm follows both versions of an **Open Business Model** Pattern. Aistech "*outside-in*" modality is portrayed with the GomSpace contracts. It develops its CubeSats with GomSpace, which applies its technology, expertise, and hardware on the satellites. Its "*inside-out*" modality comes with the offer of on-demand analytics projects. Aistech's powerful analytics platform will be able to handle more data than its space-sensed. The company knows about its extra analysis capacity and offers it for customized projects to external parties. Aistech also sealed an agreement with A&M in which both Pattern modalities are present. The two companies will share their ADS-B and AIS data with the other to expand their data sets.

This NewSpace Geospatial-Intelligence company shows a **Democratizing Business Model Pattern**. Aistech democratizes access to space knowledge, providing valuable information through its captured Earth's surface data that enables customers' decision-making processes. This Pattern suits the best with Aistech, as the Pattern common aspects explain below [21].

Open the market to everyone: Aistech targets multiple customers from ten identified markets. Its ADS-B, AIS, MS imagery, and analytics value propositions aim as many clients as possible, providing valuable space information about their activities and facilitating their decision-making process. Aistech focuses on the development, sales, and distribution of its service-oriented products. Besides, the products could turn out valuable in unexpected sectors once the constellations are operative.

Lowering the price and adding value to the services: The company will offer low-priced services due to its cost-efficient methods to sense data from space. CubeSats technology incorporates standard and predictable designs that lower its unit costs. The company satellite acquisitions from GomSpace reduce prices through lower fixed costs and infrastructure investments. Aistech's service-oriented and customer-comes-first mentality will provide quality products based on its data analytics platform. Together with the data delivery through a customer-friendly API, they will add massive value to the services.

Automated channels and customer relationships: The current Aistech situation indicates that relationships and channels still rely heavily on personal interaction, especially with the sales teams. However, communications are mostly done through the Internet and will presumably become more automated. The data delivery from space and the analytics platform, similar to Spire Global, may happen automatically through an IT platform (an API) once the products are in full service.

Have a large number of partnerships: Aistech Space has worked out partnerships to boost its development as a start-up, produce and launch satellites, and share valuable data. Remarkable is Aistech's partnership with GomSpace, which from a strong, established position, provides the satellite infrastructure and allows the company to center its efforts on product development and sales. Partnerships like with Tracasa help Aistech to understand unexplored markets and develop new technologies. The company is still in an early development stage and will need more partnerships with sector-leading firms to strengthen its brand, although actions like the Luxembourgian office opening will bring them.

Reducing variable costs: The firm reduces variable costs by integrating IT platforms, standard methodologies, and using CubeSats. Aistech buys these satellites to GomSpace after a joint development, reducing manufacturing costs. Automation in data acquisition, downlink, analysis, and delivery will likewise be essential for this purpose.

The study on Aistech Space Patterns shows that the Democratizing Business Model covers the other identified Patterns. The company's service-oriented mentality, data products, and cloud-based analytics platform will serve to "*Add value to the services.*" Investments to earn a large wallet share and an economy of scope aim to "*Open the market to everyone*," covering the Customer Relationship Management Pattern. The Open Business Model Pattern has its characteristics embraced with "*Having a large number of partnerships.*" Further, the importance of GomSpace's partnership reaches the "*Lowering the price*" and "*Reducing the variable costs*" aspects. Hence, the Pattern that best fits the NewSpace company Aistech Space is the **Democratizing Business Model Pattern**.

8.5 Success Factors

The analysis of Spire Global, GomSpace, and Aistech Space continues with their Key Success Factors. They are the most characteristic features of the businesses to succeed. The analyzed NewSpace companies already showed a common predominant Democratizing Business Model Pattern. They also turned out to share some of their Success Factors, as one could expect. The Factors that **the three companies** share are below.

Use of CubeSat Technology: The standardized CubeSat Technology allows the companies to reduce costs, development time, and modularize components to quickly carry out technological updates. CubeSats have low unit costs and short operational lives, so constellation renewal is constant. It improves satellite capabilities or increases its sales. Spire and Aistech use CubeSats, while GomSpace focuses on producing and integrating of everything associated with these Nanosats.

Continuous product innovation: The NewSpace growth rate requires that firms continuously innovate in their value propositions. The three companies are regularly investigating and improving its satellite subsystems or analytics platforms to support their distinctive characteristics. They see their products as ever-evolving outputs, not one-time releases.

Exploit unused resources in secondary products: Spire Global exploits its capacity to produce CubeSats by offering customizable data collection satellites. Aistech Space does something similar with analytics projects, offering on-demand its robust platform. The two companies focus on selling data as primary value propositions, but these secondary products can generate extra revenue at little cost. GomSpace sector position has allowed it to offer additional services on engineering, launching, and bureaucratic support. It complements the primary CubeSats systems production.

Offices expansion to NewSpace friendly countries: The companies have opened new offices around the globe to promote operations in the regions and set up new partnerships. A shared pattern was observed, selecting similar locations where local governments sponsor NewSpace corporations with grants, investments, or partnerships. All the companies have offices in Luxembourg, while Spire and GomSpace also have in Singapore.

Due to the different stages of the companies' development and market objectives, some Success Factors are shared only by **two firms**.

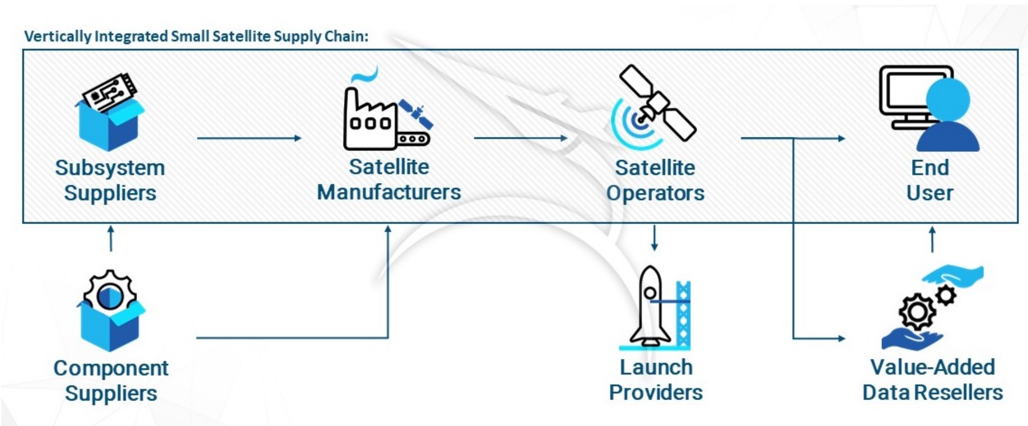


Figure 8.1: New Smallsat production Value Chain. *Image Credit: Williams and DelPozzo [225].*

Application of Vertically Integrated Strategies (VIS): A firm brings in-house the value chain elements that used to be out-sourced. It can be upstream or downstream, depending on the direction of the end-user and the company's position. Figure 8.1 presents a typical Smallsat value chain of a vertically integrated company. This strategy helps to increase efficiency, market power and quality, reduce costs and supplier risks, and enable economies of scale. However, these advantages need to outweigh high setup costs and integrated operations risks [225]. **Spire** owns the entire value chain, except the launching element, while **GomSpace** supplies subsystems, manufactures satellites, and is starting to perform commercial satellite operations.

Employment of Lean Manufacturing methods: The two companies that produce satellites have adopted Lean Manufacturing methods to succeed. They involve using COTS components, process automation, and have been useful to reduce production time and costs. **Spire Global** implements a Kaizen philosophy to improve iteratively under its Constant New Product Introduction Model continuously. Likewise, **GomSpace** has developed various methods to Reduce Development Time.

Cloud-based platforms for analytics and data sharing: Spire and **Aistech** are developing platforms to automatically downlink, perform analytics, process, and deliver the space-sensed data. They carry out Machine Learning, AI, and could deliver the data through customer-friendly APIs, adding value to the service.

Use of satellite constellations: A CubeSat constellation of multiple satellites provides worldwide coverage with high temporal resolution. **Spire** and **Aistech** use satellite constellations of over 100 CubeSats to sense Earth data remotely.

Even though the companies' dominant Pattern is the same, their success can come from distinct paths. Spire's totality of Success Factors has already been explained, but GomSpace and Aistech still base their success on other characteristics.

Binging the Radio Frequency technology to space: GomSpace founders developed the company based on their RF expertise. It has been the technological drive for the CubeSats value propositions.

Implementation of Spin-off strategies: To test its new technology in untouched domains, **GomSpace** does spin-out activities. External companies take assets, employees, product lines, or technologies from the Group to achieve success with lower risks for GomSpace.

Offering Constellation Management commercial services: The building-up of the satellite operations service in Luxembourg (the MCOP project) provides **GomSpace** new growth opportunities. It will own a new value chain element, strengthening its VIS.

Focusing on value-added services: Aistech focuses on developing its analytics platform, data sales, and API for data delivery. It relies on GomSpace to manufacture the constellation satellites and could out-source its operations to third companies.

8.6 Results Analysis

The three companies have shown a dominant **Democratizing Business Model Pattern** and similar core Key Success Factors. Table 8.2 summarizes the applicability of each factor to the companies. The similarities between these NewSpace businesses do not seem to come by chance. They all try to democratize some part of the market with revolutionary satellite manufacturing methods, cost-effective business models that center value-added services in commercial customers, and disruptive technologies in ADS-B, AIS, optical EO, RF, or cloud-based analytics platforms.

Table 8.2: Key Success Factors of Spire Global, GomSpace and Aistech Space.

Key Success Factor	Company
Use of CubeSat Technology	
Continuous product innovation	
Exploit unused resources in secondary products	
Offices expansion to NewSpace friendly countries	
Application of Vertically Integrated Strategies	
Employment of Lean Manufacturing methods	
Cloud-based platforms for analytics and data sharing	
Use of satellite constellations	
Binging the Radio Frequency technology to space	
Implementation of Spin-off strategies	
Offering Constellation Management commercial services	
Focusing on value-added services	

The NewSpace companies studied by Canyelles Pascual [21] also present similar characteristics. Satellogic and BlackSky Global were the developing roots of her Democratizing Business Model Pattern. The two firms focus on EO imagery from space, sharing some mentioned success factors. They both have Smallsats constellations that, like CubeSats, provide high revisit frequencies, reduced costs, operational lives, and development times, but fewer standardizations. Their products and satellite payloads are under constant development, as well as their powerful cloud-based analytics platforms, providing value-added imagery services. On the one hand, Satellogic follows VIS, integrating from Lean Manufacturing satellite production to data selling and delivery. On the other hand, BlackSky Global concentrates on its clients, developing a customer-oriented platform, adding value to its services, and outsourcing the upstream value chain elements to its parent company Spacecraft Industries.

Observing the five businesses, NewSpace companies seem to follow two tendencies. Spire Global, GomSpace, and Satellogic are developing VIS to control many elements of the modern satellite manufacturing Value Chain. These strategies advantages outweigh in these companies the initial high costs and risks arising from integrating operations. At the same time, Aistech Space and BlackSky Global are focusing on their value-added data services and end-users. Outsourcing the upstream elements of the Value Chain reduces costs and risks involved in manufacturing execution.

The increase of VIS in companies like Spire or Satellogic comes from the needs of satellite constellations and the underperformance of traditional space component suppliers. NewSpace companies require flexibility, high performance, and speed to succeed, but suppliers were delivering unreliable hardware or with delays. In contrast, VIS allow companies to produce quality components with quicker design iterations, tailored performances, traceable failures, reduced testing times, and standard interfaces. They enable economies of scale, increase market power, eliminate supplier risks, and lower costs. A reasonable break-even point between VIS and traditional strategies covers the initial high costs. For a 3U CubeSat constellation, the point is reached at 88 operational satellites for USD 195k per unit [225].

Aistech Space and BlackSky Global focus on developing payloads and analytics engines. This customer-center approach adds value to their services, avoiding components manufacturing distractions. Moreover, the firms could reduce the costs of expensive setup infrastructure and its associated risks. I.e., Aistech gets its satellites from GomSpace, which aims to democratize the Nanosats technology and has a dominant market position. Hence, Aistech can concentrate on its actual goal of selling insights, strengthening, and developing its market position, knowing GomSpace will deliver high-quality platforms.

The NewSpace sector has no obvious success strategy for everybody, and the market could take a 180 degrees turn in the future. The VIS of operators such as Spire Global or Satellogic may not be so irresistible in some years. Some have stated that they adopt the strategy out of necessity and not desire. They would prefer to come back to traditional procurement models to focus on developing payloads and analytics engines [225]. Therefore, they would follow strategies similar to Aistech or BlackSky Global if the suppliers' conditions allow. It is reflected in Spire's move to contract external ground station capacity, liberating efforts from its network, and preparing for an eventual closedown. In this scenario, the GomSpace model would stand out. If integrated operators want to reduce their integration, integrated suppliers like GomSpace can pick up the gauntlet and offer all CubeSat-related products and activities with similar VIS.

Coming back to the three studied companies, they all have strong success potential. Spire Global and GomSpace are the most established, giving them the success edge over Aistech. In this industry, where first-to-market companies obtain big rewards more often than in others, speed and flexibility are key. Those characteristics, together with VIS, gave Spire and GomSpace powerful market positions. The actual market situation seems to favor Spire, as the economic health of its large-constellation client, Sky and Space Global, severely affected GomSpace. After being close to bankruptcy, GomSpace will restructure its strategy to avoid revenues concentration in a few big customers. The current COVID-19 pandemic will affect the sector profoundly. Companies in weak market positions like Aistech may have to fuse with firms focused on other value chain elements to survive, following a Spire-like approach. Hence, **Spire Global is the most successful of the studied companies**, but the future of the sector could see the three succeed in its areas.

9 | Closure

9.1 Environmental Study

This Business Model study of EO companies at VLEO has no environmental impact whatsoever. It only consisted on research, investigation, and analysis of the data gathered.

9.2 Conclusions

The three commercial EO companies studied, with Nanosats in LEO, pertain to the new private spaceflight industry, known as NewSpace. This sector's growth and commercialization motivated the investigation to understand the reasons behind, reflected in the Business Model analysis and Key Success Factors of Spire Global, GomSpace, and Aistech Space. The Case Study Methodology was used to collect information and develop a BMC for each firm, illustrating their Business Models to find Patterns.

Spire Global specializes in space-to-cloud data analytics, providing advanced solutions for aviation, maritime, and weather tracking to end-users through added-value services. Its CubeSat constellation, with over 100 units, is built in-house, taking advantage of its Vertically Integrated Strategies (VIS). The firm owns all its value chain elements except the launching and has a flat hierarchy structure. Spire's Kaizen philosophy, under the iterative Constant New Product Introduction Model, reduces manufacturing costs and times on Nanosats, ground station network, and cloud-based analytics platform.

The GomSpace Group provides Nanosat solutions for space businesses based on advanced radio technology. Under its structured enterprise, the Group develops subsystems, payloads, and CubeSats using Lean Manufacturing and VIS. GomSpace focuses on CubeSats for their high Return of Investment, achieved through faster and cheaper production. Thus, the company underwent a flotation to acquire more capital and ramp-up its productions into high-volumes. The firm is developing a satellite operations service to increase its VIS value chain implication, only staying away from end-users. Its operational CubeSats come from IOD partnerships or spin-out strategy contracts, developing its technology and using them for activities in new untouched domains. GomSpace almost went into bankruptcy in 2019 due to the economic condition of a large constellation customer. Hence, the Group is trying to divide revenues into more clients as its economic position still requires investments to grow.

Aisetch Space aims to democratize access to space knowledge through Nanosats, offering added-value services to improve customers' decision-making process. This geospatial intelligence company has an early development stage compared to Spire and GomSpace but will provide space-based EO imagery, aviation, and maritime tracking. Aistech focuses on the end-user, evolving its cloud-based analytics platform, API, and payloads. It outsources the other value chain elements to reduce costs, with GomSpace developing and manufacturing Aistech's Danu and Hydra constellations.

The Pattern that best fits the three companies is the **Democratizing Business Model Pattern**. They are opening the market to new customers, reducing prices and variable costs in their activities, developing vast partnership networks, adding value to their products, and automating customer relationships. The firms' common Key Success Factors back up these characteristics. CubeSats technology, Nanosats constellations, and Lean Manufacturing are crucial to mitigate costs and lower prices. Innovative added-value products attract new customers. The development of cloud-based analytics platforms and APIs add value to the services and automatizes channels and customer relationships. The companies' partnership networks are growing through IOD projects, key activities contracts, spin-off strategies, and expansions with offices in new countries.

Other Key Success Factors contribute to the Democratizing Pattern characteristics but have a different primary goal. Spire, GomSpace, and Aistech need to continuously innovate their value propositions to avoid losing their distinctive qualities. The NewSpace growth rate requires that products are ever-evolving outputs, not one-time releases. In the same way, they exploit unused resources to create secondary products at a minimal cost. Spire offers customizable data collection satellites based on its infrastructure, Aistech does on-demand analytics projects with its robust platform, and GomSpace supports customers with engineering, launching, and bureaucratic assistance.

The VIS observed in Spire Global and GomSpace increase efficiency, market power and quality, reduce costs and supplier risks, and enable economies of scale. They are very attractive but come at high setup costs and integrated operations risks. Aistech's approach, focusing on the end-user and its added-value service, responds to a more traditional method, where the company's success depends highly on suppliers. The firms analyzed by Canyelles Pascual [21] respond to a similar trend; Satellogic lines up with Spire, while BlackSky Global does with Aistech. This comparison not only strengthens the statement of an existing Democratizing Business Model Pattern for space but opens the door to two strategies.

Inside the VIS space companies, two trends were observed; the integrated operators, who own the entire value chain elements, and the integrated suppliers, who provide the elements not related to the end-user. Integrated operators, like Spire Global or Satellogic, have stated that this strategy sometimes comes out of necessity because suppliers underperform. They would prefer to focus on end-users, developing payloads, and analytics engines. If these operators follow an Aistech-like strategy, integrated suppliers like GomSpace can pick up the gauntlet, offering their products with similar VIS advantages.

The tendency observed in Spire showed that a process of disintegration to focus on end-users was starting, but the COVID-19 crisis may slow it down. New integrated operators could arise out of necessity to survive from alliances or buyouts of smaller companies specialized in a single value chain element. Hence, VIS will dominate the NewSpace sector until the world economy improves, and the sector becomes stable, profitable, and its technologies consolidate. Then, a transition to a more fragmented market could spur the sector's innovation.

The EO companies presented in Tables 2.1, 2.2, and 2.3, can be classified in the two integration strategies. Although they did not undergo an in-depth analysis in this project, the contractor column indicating the leading satellite manufacturer can throw light to the segregation. Thus, in addition to Spire and Satellogic, Surrey Satellite Tech, Chang Guang STL, Zhuhai Orbital Aerospace, and Planet Labs may follow VIS. On the other hand, Maxar Technologies, Spot Image, Beijing Space View Technology, and GeoOptics seem to be more specialized in the end-user. It is observed how the smaller the used satellites, the more tendency to VIS exists. Hence, NewSpace has attracted to these strategies. A more in-depth analysis of these companies and similar would be interesting to understand better the market.

The three studied businesses are democratizing space with revolutionary satellite manufacturing methods, disruptive technologies, and cost-effective business models that center value-added services in commercial customers. **The most prosperous among them is Spire Global** with its market position, VIS strategy, strategy, development stage, CubeSats constellation, Lean Manufacturing, and product innovation. Thus, a new company entering the space EO sector should establish Spire Global's Key Success Factors.

9.3 Limitations and Further Research

This study is a contribution to a bigger analysis of the NewSpace EO sector. The time and resources constrains limited the analysis to only three companies of the sector. In order to validate its findings it is necessary to investigate on larger numbers of businesses. The Democratizing Business Model Pattern in space could be further developed with new findings. Aiming to understand the relationship between a successful NewSpace company and the VIS, firms could be selected for analysis regarding its status of integrated operators, integrated suppliers, or specialized in one value chain element, especially the end user. Hence, a better understanding of this fast-growing and evolving market would result.

(This page was intentionally left in blank.)

Bibliography

[1] ÅAC MICROTEC. ÅAC MICROTEC WINS ORDER FOR SUBSYSTEMS FOR 10 SATELLITES FROM AISTECH. [Online], may 2018. URL https://investor.aac-clyde.space/se/pressmeddelanden/aac-microtec-wins-order-for-subsystems-for-10-satellites-fro-65147. [Accessed on: 2019-12-02].

[2] Adafruit, SparkFun, and Pololu. ArduSatSDK. [Online], 2016. URL https://github.com/ArduSat/ArduSatSDK. [Accessed on: 2019-01-20].

[3] Agencia EFE. Aistech Space dispondrá de una constelación de más de 150 satélites en 2022. [Online], mar 2019. URL https://www.efe.com/efe/espana/efeempresas/aistech-space-dispondra-de-una-constelacion-mas-150-satelites-en-2022/50000908-3925811. [Accessed on: 2019-12-03].

[4] Agencia Gallega de Innovación. DOG Núm. 237, 14 de diciembre de 2016. *Diario Oficial de Galicia*, (237, December 14th):54521–54525, 2016. URL https://www.xunta.gal/dog/Publicados/2016/20161214/AnuncioG0198-051216-0001{_}es.html.

[5] Aistech Space. LA FÁBRICA DEL FUTURO APLICADA AL DESARROLLO DE UNA CONSTELACIÓN DE SATÉLITES DE OBSERVACIÓN, COMUNICACIONES Y CONTROL MARÍTIMO Y AÉREO. [Online], dec 2016. URL http://aistechspace.com/. [Accessed on: 2019-11-25].

[6] Aistech Space. Aistech Space. [Video], mar 2016. URL https://www.youtube.com/watch?v=QddvTHVFofg.

[7] Aistech Space. Aistechsat-1. [Video], jun 2016. URL https://youtu.be/7zukzaAYGM0.

[8] Aistech Space. Aistech Space signs a Memorandum of Understanding with GomSpace for the delivery of 100 nanosatellite platforms. [Online], jun 2017. [Accessed on: 2019-12-01].

[9] Aistech Space. Aistech, Access to Inteligent Space Technologies. [Online], 2019. URL http://aistechspace.com. [Accessed on: 2019-12-29].

[10] Aistech Space. Our Fleet. [Online], 2019. URL http://aistechspace.com/fleet. [Accessed on: 2020-01-05].

[11] Ajuntament de Barcelona. Gaseta Municipal de Barcelona, Núm. 34 / Any CII, 20 de desembre de 2015. *Gaseta Municipal de Barcelona*, (34, December 5th):6464–6663, 2015.

[12] Alan. Space Data Start-Up Raises $1.3M from Angels, Crowdfunding. [Online], feb 2013. URL https://sciencebusiness.technewslit.com/?p=12853. [Accessed on: 2018-12-10].

[13] L. K. Alminde, K. Kaas, M. Bisgaard, J. Christiansen, and D. Gerhardt. GOMX-1 Flight Experience and Air Traffic Monitoring Results. In *28th Annual AIAA/USU Conference on Small Satellite*, pages 1–7, Logan, Utah, USA, 2014. GomSpace ApS, GomSpace ApS.

[14] C. Anderson, C. Brunskill, and C. Guillo. SMALL IS THE NEW BIG - Nano/Micro-Satellite Missions for Earth Observation and Remote Sensing. Technical report, Satellite Applications Catapult, Didcot, UK, 2014.

[15] Artes - ESA. FROM SATELLITES TO THE SEA: VDES OFFERS GLOBAL LINK FOR SHIPS. [Online], jan 2018. URL https://artes.esa.int/news/satellites-sea-vdes-offers-global-link-ships. [Accessed on: 2019-05-22].

[16] B. A. Banks, K. K. de Groh, and S. K. Miller. Low Earth Orbital Atomic Oxygen Interactions with Spacecraft Materials. *MRS Proceedings*, 851(November 2004):NN8.1, 2004. ISSN 1946-4274. doi: 10.1557/PROC-851-NN8.1.

[17] Barcelona Activa. 'Start-up' Aistech Space, al 4YFN. [Video], feb 2016. URL https://youtu.be/Y1mDXSx4hTI.

[18] J. Barna. NanoRacks-LEMUR-2. [Online], jan 2019. URL https://www.nasa.gov/mission{_}pages/station/research/experiments/2349.html. [Accessed on: 2019-01-29].

[19] J. Barnes. Drones vs Manned Aircraft - Which Tool is Right for Your Project? - Commercial UAV News. [Online], apr 2018. URL https://www.expouav.com/news/latest/drones-vs-manned-aircraft/. [Accessed on: 2018-09-29].

[20] D. Bryce and J. Cappaert. SSC11-I-6 Conference on Small Satellites Conference on Small Satellites. In *33rd Annual AIAA/USU Conference on Small Satellite*, pages 1–6, Logan, Utah, USA, 2019. Spire Global UK Ltd.

[21] M. C. Canyelles Pascual. *Study of Earth Observation Business Models by means of Business Models Methodologies*. Bachelor's degree in aerospace technologies engineering, Universitat Politècnica de Catalunya, 2019.

[22] J. Cappaert. Building , Deploying and Operating a Cubesat Constellation - Exploring the Less Obvious Reasons Space is Hard. In *32nd Annual AIAA/USU Conference on Small Satellites*, pages 1–7, Logan, UT, USA, 2018. Spire Global UK Ltd.

[23] CDTI. Proyectos CDTI aprobados. Primer semestre de 2019. [Online], jun 2019. URL http://cdtioficial.es/recursos/doc/Proyectos{_}aprobados/30129{_}119119201910280.xlsx. [Accessed on: 2020-01-20].

[24] J. Chang and D. E. Clay. Matching Remote Sensing to Problems. In D. Clay, S. Clay, C. Carlson, and E. Byamukama, editors, *iGrow Corn: Best Management Practices*, chapter 22, page 6. South Dakota State University, 2016.

[25] C. W. Chen and A. Moussessian. MEO SAR System Concepts and Technologies for Earth Remote Sensing. In *AIAA Space 2004 Conference and Exhibit*, number September,

page 6, San Diego, USA, 2004. Jet Propulsion Laboratory. ISBN 1563477203. doi: 10.2514/6.2004-5904.

[26] J. Chin, R. Coelho, J. Foley, A. Johnstone, R. Nugent, D. Pignatelli, S. Pignatelli, N. Powell, J. Puig-Suari, W. Atkinson, J. Dorsey, S. Higginbotham, M. Krienke, K. Nelson, B. Poffenberger, C. Raffington, G. Skrobot, J. Treptow, A. Sweet, J. Crusan, C. Galica, W. Horne, C. Norton, and A. Robinson. CubeSat 101: Basic Concepts and Processes for First-Time CubeSat Developers. Technical Report October, NASA CubeSat Launch Initiative, 2017.

[27] Corporate Finance Institute. Spin-off. [Online], 2019. URL https://corporatefinanceinstitute.com/resources/knowledge/finance/spin-off-and-split-off/. [Accessed on: 2019-08-05].

[28] Crunchbase Inc. Spire Global Inc. [Online], 2017. URL https://www.crunchbase.com/organization/spire{#}section-overview. [Accessed on: 2018-12-10].

[29] I. de las Heras. La española Aistech busca junto a Rothschild 25 millones para desplegar nanosatélites. [Online], dec 2018. URL https://www.expansion.com/empresas/tecnologia/2018/12/27/5c24afb6268e3e242c8b45bb.html. [Accessed on: 2019-05-15].

[30] G. J. Dittberner, A. J. Gerber, D. Tralli, and S. N. Bajpai. Medium Earth orbit (MEO) as a venue for future NOAA satellite systems. Technical report, Jet Propulsion Laboratory, 2005.

[31] Earth Observation Data Centre for Water Resources Monitoring. Wegener Center GNSS Radio Occultation Record. [Online], 2017. URL https://www.eodc.eu/data-services/wegc-gnss-ro/. [Accessed on: 2019-05-22].

[32] J. Eddy. UAVs vs MAVs. *GIS Professional*, 63(4):20–21, 2015.

[33] eoPortal - ESA. GOMX-1 (GomSpace Express-1). [Online], 2014. URL https://directory.eoportal.org/web/eoportal/satellite-missions/g/gomx-1{#}mission-status. [Accessed on: 2019-05-21].

[34] eoPortal - ESA. GOMX-3 (GomSpace Express-3). [Online], 2017. URL https://directory.eoportal.org/web/eoportal/satellite-missions/g/gomx-3. [Accessed on: 2019-05-24].

[35] eoPortal - ESA. Satellite Missions Directory - Earth Observation Missions. [Online], 2018. URL https://directory.eoportal.org/web/eoportal/satellite-missions. [Accessed on: 2018-12-06].

[36] eoPortal - ESA. GomX-4 (GomSpace Express-4) Mission. [Online], 2019. URL https://directory.eoportal.org/web/eoportal/satellite-missions/g/gomx-4. [Accessed on: 2019-05-24].

[37] ESA. M-ARGO. [Online], jun 2017. URL http://www.esa.int/spaceinimages/Images/2017/06/M{_}Argo. [Accessed on: 2019-07-23].

[38] ESA. OPS-SAT. [Online], apr 2017. URL https://www.esa.int/Our{_}Activities/Operations/OPS-SAT. [Accessed on: 2019-06-06].

[39] ESA. SAGAS - SATELLITE AUGMENTED GLOBAL AIRCRAFT SURVEILLANCE. [Online], jun 2018. URL https://business.esa.int/projects/sagas. [Accessed on: 2019-06-06].

[40] ESA and NRSCC. Dragon 4 Cooperation Proposal, Informatopn for scientists. Technical Note, 2015.

[41] EU Publications Office. Technology for Self Removal of Spacecraft. [Online], jul 2017. URL https://cordis.europa.eu/project/rcn/200248/factsheet/en. [Accessed on: 2019-06-06].

[42] European Facility for Airborne Research. Aircraft: BAe146 - FAAM. [Online], 2018. URL http://www.eufar.net/aircrafts/21/details/. [Accessed on: 2018-10-01].

[43] W. Fernandez and S. Preston. LAUNCHING AIRCRAFT SURVEILLANCE IN SPACE. Technical report, Spire Global Inc., San Francisco, CA, USA, 2018.

[44] R. Fleeter. Small Satellite Technology. [Online], 2002. URL https://www.encyclopedia.com/science/news-wires-white-papers-and-books/small-satellite-technology. [Accessed on: 2018-11-12].

[45] Flux Podcast. 05: Peter Platzer - Weather Wizard. [Online], feb 2017. URL https://blog.rre.com/05-peter-platzer-weather-wizard-48ff9504ceb2. [Accessed on: 2018-12-10].

[46] C. Franquesa. Carles Franquesa. [Online], 2019. URL https://www.linkedin.com/in/carles-franquesa-027a537/. [Accessed on: 2019-11-22].

[47] Freetronics Pty Ltd. LibreSat Payload Processor Module. [Online], 2016. URL https://www.freetronics.com.au/collections/ardusat/products/ardusat-payload-processor-module{#}.XGFZdC2ZNsM. [Accessed on: 2019-01-15].

[48] D. A. Gardiner. Space based ADS-B using NANOSATS. Presentation, 2018.

[49] D. Gerhardt, M. Bisgaard, L. Alminde, R. Walker, M. A. Fernandez, A. Latiri, and J.-L. Issler. GOMX-3: Mission Results from the Inaugural ESA In-Orbit Demonstration CubeSat. In *30th Annual AIAA/USU Conference on Small Satellite*, pages 1–9, Logan, Utah, USA, 2016. GomSpace ApS.

[50] GIS Professional. Spire Global Data Integrated with ArcGIS. [Online], apr 2018. URL https://www.gis-professional.com/content/news/spire-global-data-integrated-with-arcgis. [Accessed on: 2019-05-02].

[51] Glassdoor Inc. GomSpace Interview Questions. [Online], sep 2016. URL https://www.glassdoor.com/Interview/GomSpace-Interview-Questions-E1371318.htm. [Accessed on: 2019-05-29].

[52] Glassdoor Inc. Working at Spire Global. [Online], 2018. URL https://www.glassdoor.com/Overview/Working-at-Spire-Global-EI{_}IE794910.11,23.htm. [Accessed on: 2018-12-22].

[53] Globe Newswire. Spire Taps Galileo for Space-Based Weather Data. [Online], dec 2018. URL https://globenewswire.com/news-release/2018/12/11/1665433/0/en/Spire-Taps-Galileo-for-Space-Based-Weather-Data.html. [Accessed on: 2018-12-21].

[54] GomSpace. 1U/2U Platform. [Online], 2019. URL https://gomspace.com/1u-2u-platform.aspx. [Accessed on: 2019-08-03].

[55] GomSpace. 3U Platform. [Online], 2019. URL https://gomspace.com/3u-platform.aspx. [Accessed on: 2019-08-03].

[56] GomSpace. 6U Platform. [Online], 2019. URL https://gomspace.com/6u-platform.aspx. [Accessed on: 2019-08-03].

[57] GomSpace. ADCS Software. [Online], 2019. URL https://gomspace.com/shop/subsystems/attitude-orbit-control-systems/adcs-software.aspx. [Accessed on: 2019-07-29].

[58] GomSpace. Command and Data Handling. [Online], 2019. URL https://gomspace.com/shop/subsystems/command-and-data-handling/default.aspx. [Accessed on: 2019-07-25].

[59] GomSpace. Communications. [Online], 2019. URL https://gomspace.com/communications.aspx. [Accessed on: 2019-06-03].

[60] GomSpace. Communication Systems. [Online], 2019. URL https://gomspace.com/shop/subsystems/communication-(1)/default.aspx. [Accessed on: 2019-07-27].

[61] GomSpace. Constellation Management. [Online], 2019. URL https://gomspace.com/constellation-management-(1).aspx. [Accessed on: 2019-08-03].

[62] GomSpace. Attitude and Orbit Control Systems. [Online], 2019. URL https://gomspace.com/shop/subsystems/attitude-orbit-control-systems/default.aspx. [Accessed on: 2019-07-29].

[63] GomSpace. Defence and Security. [Online], 2019. URL https://gomspace.com/defence-and-security.aspx. [Accessed on: 2019-06-03].

[64] GomSpace. Payload collaboration initiated for the GOMX-5 mission. [Online], jun 2019. URL https://gomspace.com/news/payload-collaboration-initiated-for-the-gomx-.aspx. [Accessed on: 2019-07-23].

[65] GomSpace. Meet Us. [Online], 2019. URL https://gomspace.com/meet-us.aspx. [Accessed on: 2019-05-29].

[66] GomSpace. Our Values. [Online], 2019. URL https://gomspace.com/our-values.aspx. [Accessed on: 2019-05-29].

[67] GomSpace. GomSpace to design world's first stand-alone nanosatellite asteroid rendezvous mission. [Online], may 2019. URL https://gomspace.com/news/gomspace-to-design-worlds-first-stand-alone-n.aspx. [Accessed on: 2019-07-23].

[68] GomSpace. Products. [Online], 2019. URL https://gomspace.com/shop/subsystems/default.aspx. [Accessed on: 2019-07-25].

[69] GomSpace. Annual general meeting held in GomSpace Group AB (publ). [Online], apr 2019. URL https://news.cision.com/gomspace-a-s/r/annual-general-meeting-held-in-gomspace-group-ab--publ-,c2798046. [Accessed on: 2019-05-22].

[70] GomSpace. GomSpace News. [Online], 2019. URL https://gomspace.com/news.aspx?page=42. [Accessed on: 2019-05-24].

[71] GomSpace. Platforms. [Online], 2019. URL https://gomspace.com/platforms.aspx. [Accessed on: 2019-07-30].

[72] GomSpace. Remote Sensing. [Online], 2019. URL https://gomspace.com/remote-sensing.aspx. [Accessed on: 2019-06-03].

[73] GomSpace. Science Missions. [Online], 2019. URL https://gomspace.com/science-missions.aspx. [Accessed on: 2019-06-03].

[74] GomSpace. Platform Software. [Online], 2019. URL https://gomspace.com/shop/subsystems/command-and-data-handling/platform-software.aspx. [Accessed on: 2019-07-27].

[75] GomSpace. Solutions. [Online], 2019. URL https://gomspace.com/solutions.aspx. [Accessed on: 2019-06-03].

[76] GomSpace. The Story. [Online], 2019. [Accessed on: 2019-05-21].

[77] GomSpace ApS. Profile - Company Introduction. [Online], sep 2013. URL https://web.archive.org/web/20130923154148/http://gomspace.com/index.php?p=profile. [Accessed on: 2019-05-21].

[78] GomSpace A/S. NanoTorque Z-Axis Internal Datasheet. Datasheet, oct 2016.

[79] GomSpace A/S. NanoCam C1U Datasheet. Datasheet, oct 2017.

[80] GomSpace A/S. NanoMind A3200 Datasheet. Datasheet, jun 2018.

[81] GomSpace A/S. Datasheet NanoPower BP4. Datasheet, oct 2018.

[82] GomSpace A/S. NanoPower BPX Datasheet. Datasheet, may 2018.

[83] GomSpace A/S. Datasheet NanoTorque GST-600. Datasheet, oct 2018.

[84] GomSpace A/S. Datasheet NanoTorque GSW-600. Datasheet, sep 2018.

[85] GomSpace A/S. Datasheet NanoCom ADSB. Datasheet, dec 2018.

[86] GomSpace A/S. Datasheet NanoCom ANT1090-P. Datasheet, sep 2018.

[87] GomSpace A/S. GomSpace and AISTECH Sign New Agreement. [Online], jul 2018. URL https://www.prnewswire.com/news-releases/gomspace-and-aistech-sign-new-agreement-300681194.html. [Accessed on: 2019-12-02].

[88] GomSpace A/S. Datasheet NanoCom SDR: SDR Dock, Z7000 and TR-600. Datasheet, nov 2018.

[89] GomSpace A/S. Datasheet NanoPower P110. Datasheet, oct 2018.

[90] GomSpace A/S. NanoPower Power Packs. Datasheet, oct 2018.

[91] GomSpace A/S. Datasheet NanoPower Deployable Solar Panel. Datasheet, mar 2019.

[92] GomSpace A/S. Datasheet NanoSense Fine Sun Sensor. Datasheet, may 2019.

[93] GomSpace A/S. Datasheet NanoSense GPS Kits. Datasheet, jan 2019.

[94] GomSpace A/S. Datasheet NanoSense M315. Datasheet, jun 2019.

[95] GomSpace A/S. Datasheet NanoPower MSP. Datasheet, mar 2019.

[96] GomSpace A/S. Datasheet NanoPower P31u. Datasheet, jan 2019.

[97] GomSpace A/S. NanoProp CGP3. Flyer, 2019.

[98] GomSpace A/S. NanoProp 6U. Flyer, 2019.

[99] GomSpace A/S. Datasheet NanoMind Z7000. Datasheet, mar 2019.

[100] GomSpace Group AB. GomSpace secures new innovation project from Innovation Fund Denmark. [Online], mar 2017. URL https://gomspace.com/news/gomspace-secures-new-innovation-project-from-.aspx. [Accessed on: 2020-02-10].

[101] GomSpace Group AB. GomSpace and AISTECH sign a binding Framework Delivery Agreement for the supply of 100 Nanosatellite platforms. [Online], sep 2017. [Accessed on: 2019-05-25].

[102] GomSpace Group AB. Aerial and Maritime. [Online], 2018. URL https://gomspace.com/aerial-maritime.aspx. [Accessed on: 2019-07-24].

[103] GomSpace Group AB. Annual Report 2017. Technical report, GomSpace Group AB, Stockholm, Sweden, 2018.

[104] GomSpace Group AB. Board of Directors. [Online], 2018. URL https://gomspace.com/board-of-directors-(1).aspx. [Accessed on: 2019-05-27].

[105] GomSpace Group AB. Invitation to subscribe for shares in GomSpace Group AB Nasdaq. Technical report, GomSpace Group AB, Stockholm, Sweden, 2018.

[106] GomSpace Group AB. Nanopower P60. [Online], 2018. URL https://gomspace.com/shop/subsystems/power/nanopower-p60.aspx. [Accessed on: 2019-07-26].

[107] GomSpace Group AB. Annual Report 2018. Technical report, GomSpace Group AB, Uppsala, Sweden, 2019.

[108] GomSpace Group AB. Global Tracking. [Online], 2019. URL https://gomspace.com/global-tracking.aspx. [Accessed on: 2019-06-03].

[109] GomSpace Group AB. Investor Presentation March 2019. Presentation, mar 2019.

[110] GomSpace Group AB. Internet of Things. [Online], 2019. URL https://gomspace.com/internet-of-things.aspx. [Accessed on: 2019-06-03].

[111] GomSpace Group AB. Interim report: for 1 January – 31 March 2019. Technical Report Q1-2019, GomSpace Group AB, Stockholm, Sweden, 2019.

[112] GomSpace Group AB. Annual Report 2019. Technical report, GomSpace Group AB, Uppsala, Sweden, 2020.

[113] GomSpace Group AB and ESA. RACE DOUBLE CUBESAT MISSION. [Online], jun 2019. URL https://www.esa.int/spaceinimages/Images/2019/06/RACE{_}double{_}CubeSat{_}mission. [Accessed on: 2019-07-22].

[114] GomSpace Sweden AB. AISTECH places Order at the Sum of 200,000 € with GomSpace for the Delivery of Full Platform and Payload for their First Nanosatellite. [Online], oct 2016. URL https://mb.cision.com/Main/14387/2092745/570398.pdf. [Accessed on: 2019-12-01].

[115] GomSpace Sweden AB. Consolidated Financial Statements for 2016. Technical report, GomSpace Sweden AB, Stockholm, Sweden, 2017.

[116] GomSpace Sweden AB. Aerial & Maritime Ltd. and AISTECH Srl. enter into a mutual Data Service Agreement. [Online], mar 2017. URL https://mb.cision.com/Main/14387/2228069/650526.pdf. [Accessed on: 2019-12-01].

[117] G. Gonzalez, R. M. Dominguez, I. Vazquez, A. Braña, N. H. Crisp, and J. Becedas. VLEO Aerodynamics Requirements Document. Technical report, Discoverer, 2018.

[118] Group on Earth Observations. GEO at a Glance. [Online], 2018. URL https://www.earthobservations.org/geo{_}wwd.php. [Accessed on: 2018-09-28].

[119] J. Hay, P. Guthrie, C. Mullins, E. Gresham, and C. Christensen. Global Space Industry : Refining the Definition of New Space. In *AIAA Space 2009 Conference and Exposition*, number September, page 7, Pasadena, USA, 2009. The Tauri Group. ISBN 9781563479793.

[120] J. Hill. Spire Expands Reach into Maritime Chartering, Commodity Markets. [Online], apr 2019. URL https://www.satellitetoday.com/mobility/2019/04/12/spire-expands-reach-into-maritime-chartering-commodity-markets/. [Accessed on: 2019-05-02].

[121] V. Högberg and S. Ladow. Commissioned Research: GomSpace - Waiting for commercial customers to get the go-ahead. Technical Report December, Danske Bank A/S, Stockholm, Sweden, 2019.

[122] V. Hogberg and S. Ladow. Commissioned Research: GomSpace - Better Q1 but pandemic likely to result in order delays. Technical report, Danske Bank A/S, Stockholm, Sweden, 2020.

[123] E. Howell. Satellite Company Spire Sees High Growth Amid A Crowded Market. [Online], apr 2019. URL https://www.forbes.com/sites/elizabethhowell1/2019/04/05/satellite-company-spire-sees-high-growth-amid-a-crowded-market/{#}1072dbf4f52f. [Accessed on: 2019-05-02].

[124] ICEYE. ICEYE and Spire Join Forces To Enable Global Monitoring Of Dark Vessels At Sea. [Online], 2019. URL https://www.iceye.com/press/press-releases/iceye-spire-join-forces-enable-global-monitoring-dark-vessels-at-sea. [Accessed on: 2019-05-02].

[125] Inforiesgos S.A. Aistech Space SL. [Online], 2019. URL http://www.infocif.es/empresa/aistech-space-sl. [Accessed on: 2019-11-22].

[126] Jason Samenow. NOAA awards first-ever satellite data contracts to private industry. [Online], sep 2016. URL https://www.washingtonpost.com/news/capital-weather-gang/wp/2016/09/16/noaa-awards-first-ever-satellite-data-contracts-to-private-industry/?noredirect=on{&}utm{_}term=.2f7b0835fa0b{#}comments. [Accessed on: 2018-12-18].

[127] Jeroen Cappaert. Jeroen Cappaert. [Online], dec 2018. URL https://www.linkedin.com/in/jeroencappaert/. [Accessed on: 2018-12-23].

[128] H. J. Kramer. Lemur-2 Nanosatellite Constellation of Spire Global. [Online], 2018. URL https://directory.eoportal.org/web/eoportal/satellite-missions/l/lemur{#}foot3{%}29. [Accessed on: 2018-12-14].

[129] G. Krebs. GOMX-2. [Online], dec 2017. URL https://space.skyrocket.de/doc{_}sdat/gomx-2.htm. [Accessed on: 2019-05-22].

[130] G. Krebs. ArduSat 2. [Online], dec 2017. URL https://space.skyrocket.de/doc{_}sdat/ardusat-2.htm. [Accessed on: 2018-12-03].

[131] G. Krebs. Lemur-1. [Online], dec 2017. URL https://space.skyrocket.de/doc{_}sdat/lemur-1.htm. [Accessed on: 2018-12-03].

[132] G. Krebs. ArduSat 1, X. [Online], apr 2018. URL https://space.skyrocket.de/doc{_}sdat/ardusat-1.htm. [Accessed on: 2018-12-03].

[133] G. Krebs. Lemur-2. [Online], dec 2018. URL https://space.skyrocket.de/doc{_}sdat/lemur-2.htm. [Accessed on: 2018-12-03].

[134] G. Krebs. Spacecraft - Gunter's Space Page. [Online], nov 2018. URL https://space.skyrocket.de/directories/sat.htm. [Accessed on: 2018-12-08].

[135] G. Krebs. Starling 1 to 8. [Online], sep 2018. URL https://space.skyrocket.de/doc{_}sdat/starling.htm. [Accessed on: 2019-07-24].

[136] G. Krebs. AISTECHSAT 1, 2, 3 / Danu Pathfinder, 1, ..., 10. [Online], nov 2019. URL https://space.skyrocket.de/doc{_}sdat/aistechsat-1.htm. [Accessed on: 2019-12-03].

[137] G. Krebs. Hydra 1, ..., 18. [online], nov 2019. URL https://space.skyrocket.de/doc{_}sdat/hydra-1.htm. [Accessed on: 2020-01-05].

[138] E. Kulu. Kleos Scouting Mission. [Online], apr 2020. URL https://www.nanosats.eu/sat/kleos-scouting-mission. [Accessed on: 2020-05-10].

[139] E. Kulu. Nanosatellite Database. [Online], oct 2020. URL https://www.nanosats.eu/database. [Accessed on: 2020-05-29].

[140] B. Lal, E. De la Rosa Blanco, J. R. Behrens, B. A. Corbin, E. K. Green, A. J. Picard, and A. Balakrishnan. Global Trends in Small Satellites. Technical report, Institute for Defense Analyses, Washington, D.C., 2017.

[141] J. A. Larsen, D. Gerhardt, M. Bisgaard, L. Alminde, R. Walker, M. Fernandez, and J.-L. Issler. RAPID RESULTS: THE GOMX-3 CUBESAT PATH TO ORBIT. In *The 4S Symposium 2016*, pages 1–11, Valletta, Malta, 2016. GomSpace ApS.

[142] Latam Satelital. Aistech Space, innovación en nanosatélites desde España. [Online], jul 2016. URL http://latamsatelital.com/aistech-space-innovacion-nanosatelites-desde-espana/. [Accessed on: 2019-11-24].

[143] Luxembourg Space Agency. AISTECH SPACE. [Online], sep 2019. URL https://space-agency.public.lu/en/expertise/space-directory/AistechSpace.html{#}. [Accessed on: 2019-12-03].

[144] Luxembourg Space Cluster. Luxembourg space capabilities. *LUXEMBOURG SPACE CAPABILITIES*, (2018):103, 2018.

[145] L. Manning. Maritime Data Powerhouse Spire Announces Close of $40M Series B Round. [Online], jun 2015. URL https://agfundernews.com/maritime-data-powerhouse-spire-announces-close-of-40m-series-b-round.html/. [Accessed on: 2018-12-15].

[146] U. Martensson. *Introduction to Remote Sensing and Geographical Information Systems*. PhD thesis, University of Lund, 2011.

[147] Maxar. The Maxar Constellation. Technical Brochure, 2020.

[148] D. Messier. Spaceflight Partners with Spire, Tethers Unlimited, BitBeam & Syrlinks to Expand Global Communications. [Online], jul 2015. URL https://shar.es/aHFcSL. [Accessed on: 2019-05-02].

[149] D. Messier. Spire to Open European Headquarters in Glasgow. [Online], jun 2015. URL http://www.parabolicarc.com/2015/06/10/spire-open-european-headquarters-glasgow/. [Accessed on: 2018-12-15].

[150] M. Moalem. Quarterly Company Update and Cashflow. Technical report, Sky and Space Global Ltd, West Perth, AU, 2019.

[151] Morningstar and Nasdaq. Company Fact Sheet - GomSpace Group AB, may 2019.

[152] N. P. Nagendra and T. Segert. Challenges for NewSpace Commercial Earth Observation Small Satellites. *New Space*, 5(4):238–243, 2017. ISSN 2168-0256. doi: 10.1089/space.2017.0014.

[153] NanoRacks LLC. NanoRacks Announces First Customer Contract for India's Polar Satellite Launch Vehicle (PSLV). [Online], dec 2018. URL http://nanoracks.com/nanoracks-announces-customer-for-polar-satellite-launch-vehicle/. [Accessed on: 2019-05-02].

[154] Nanosatisfi. ArduSat - Sample Code and Sensor List. [Online], mar 2013. URL https://www.kickstarter.com/projects/575960623/ardusat-your-arduino-experiment-in-space/posts/422723. [Accessed on: 2018-12-11].

[155] National Oceanic and Atmospheric Administration. Commercial Weather Data Pilot (CWDP) - Radio Occultation (RO). [Online], sep 2018. URL https://www.fbo.gov/index?s=opportunity{&}mode=form{&}id=919a17d831c31a26a50eae5282056289{&}tab=core{&}{_}cview=1. [Accessed on: 2018-12-20].

[156] Naval-technology.com. Dassault Falcon 2000 Maritime Reconnaissance Aircraft (MRA). [Online], 2018. URL https://www.naval-technology.com/projects/dassault-falcon-2000-maritime-reconnaissance-aircraft-mra/. [Accessed on: 2018-10-01].

[157] A. Osterwalder. What is a business model? [Online], jul 2008. URL https://web.archive.org/web/20080906034734/http://business-model-design.blogspot.com/2008/07/what-is-business-model.html. [Accessed on: 2020-02-02].

[158] Owler Inc. Spire's Competitors, Revenue, Number of Employees, Funding and Acquisitions. [Online], 2019. URL https://www.owler.com/company/spire. [Accessed on: 2019-05-05].

[159] G. Pajares. Overview and Current Status of Remote Sensing Applications Based on Unmanned Aerial Vehicles (UAVs). *Photogrammetric Engineering and Remote Sensing*, 81(4):281–330, 2015. ISSN 00991112. doi: 10.14358/PERS.81.4.281.

[160] J. Pino. Aistechsat-2 TLM codes, modulation and format. Datasheet, 2019.

[161] PitchBook Data. AISTECH SPACE. [Online], 2020. URL https://pitchbook.com/profiles/company/185243-14. [Accessed on: 2020-01-20].

[162] P. Platzer. NanoRacks-ArduSat-2. [Online], nov 2016. URL https://www.nasa.gov/mission{_}pages/station/research/experiments/1327.html{#}description. [Accessed on: 2019-02-02].

[163] P. Platzer. Peter Platzer. [Online], dec 2018. URL https://www.linkedin.com/in/peterplatzer/. [Accessed on: 2018-12-23].

[164] L. Probst, L. Frideres, B. Cambier, J.-P. Duval, M. Roth, C. Lu-Dac, PwC Luxembourg, and PwC France. Applications related to Earth Observation. Technical report, Business Innovation Observatory, European Union, 2016.

[165] P. C. Roberts, N. H. Crisp, S. Edmondson, S. J. Haigh, R. E. Lyons, V. T. Oiko, A. M. Rojas, K. L. Smith, J. Becedas, G. González, I. Vázquez, Á. Braña, K. Antonini, K. Bay, L. Ghizoni, V. Jungnell, J. Morsbøl, T. Binder, A. Boxberger, G. H. Herdrich, F. Romano, S. Fasoulas, D. Garcia-Almiñana, S. Rodriguez-Donaire, D. Kataria, M. Davidson, R. Outlaw, B. Belkouchi, A. Conte, J. S. Perez, R. Villain, B. Heißerer, and A. Schwalber. DISCOVERER – Radical Redesign of Earth Observation Satellites for Sustained Operation at Significantly Lower Altitudes. In *68th International Astronautical Congress (IAC)*, number September, pages 1–9, Adelaide, Australia, 2017. International Astronautical Federation (IAF).

[166] Satlab ApS. Software-Defined AIS Receiver for CubeSats QubeAIS. Datasheet, 2017.

[167] M. Sheetz. Amazon cloud business reaches into space with satellite connection service. [Online], nov 2018. URL https://www.cnbc.com/2018/11/27/amazon-launches-aws-ground-station-satellite-data-collection-service.html. [Accessed on: 2019-05-02].

[168] M. Sheetz. Satellite builder and data business Spire raises $40 million as IPO plans come into view. [Online], sep 2019. URL https://www.cnbc.com/2019/09/25/satellite-data-company-spire-raises-40-million-with-ipo-plans-in-view.html. [Accessed on: 20-5-2020].

[169] Simply Wall Street PTY LTD. GomSpace Group. [Online], may 2019. URL https://simplywall.st/stocks/se/capital-goods/sto-gomx/gomspace-group-shares{#}ownership{_}summary?utm{_}medium=finance{_}user{&}utm{_}source=yahoo{&}utm{_}campaign=Infographic{&}blueprint=213467{%}23{_}={_}. [Accessed on: 2019-05-27].

[170] Spacecrafts and Satellites. Aleph-1 Satellite Constellation. [Online], 2016. URL http://spaceflight101.com/spacecraft/aleph-1/. [Accessed on: 2018-12-05].

[171] Spaceoneers. Interview: Peter Platzer, CEO of Spire. [Online], jan 2018. URL http://spaceoneers.io/2018/01/10/spire/. [Accessed on: 2018-12-10].

[172] Spain. Actos de BARCELONA del BORME núm. 149 de 2015. *BOLETÍN OFICIAL DEL REGISTRO MERCANTIL*, (149, August 7th):35497–35525, 2015.

[173] J. Spark. NOAA Commercial Remote Sensing Regulatory Affairs: ArduSat Public General Description. Technical report, NanoSatisfi Inc., San Francisco, CA, USA, 2012.

[174] J. Spark. NOAA Commercial Remote Sensing Regulatory Affairs: LEMUR-1. Technical report, NanoSatisfi Inc., San Francisco, CA, USA, 2014.

[175] J. Spark. Joel Spark. [Online], dec 2018. URL https://www.linkedin.com/in/joelspark/. [Accessed on: 2018-12-23].

[176] Spire Global Inc. Spire - A Name Reflective of Our High-Reaching Mission. [Online], jul 2014. URL https://spire.com/company/insights/news/spire-intro/. [Accessed on: 2018-12-12].

[177] Spire Global Inc. Exhibit A: Spire Global, Inc. Response to Question 43. FCC Form 312. Technical report, Federal Communications Commission, 2015.

[178] Spire Global Inc. Spirepedia: GNSS-RO and GPS-RO. [Online], oct 2016. URL https://www.spire.com/spirepedia/gnss-ro-amp-gps-ro. [Accessed on: 2019-01-29].

[179] Spire Global Inc. Spire Opens a European HQ in Luxembourg, Raises Additional $70M. [Online], nov 2017. URL https://spire.com/company/insights/news/spire-opens-european-hq-luxembourg-raises-addition/. [Accessed on: 2018-12-18].

[180] Spire Global Inc. NGA Project to Improve Maritime Domain Awareness in the Arctic Begins. [Online], mar 2017. URL https://spire.com/company/insights/news/spire-providing-data-nga-effort-maritime-domain-aw/. [Accessed on: 2018-12-18].

[181] Spire Global Inc. Integration Guide: GEOEVENT SERVER AND SPIRE'S AIS API. Integration Guide, 2018.

[182] Spire Global Inc. Spirepedia: ADS-B. [Online], jan 2018. URL https://www.spire.com/spirepedia/ads-b. [Accessed on: 2019-01-29].

[183] Spire Global Inc. Spirepedia: AIS. [Online], oct 2018. URL https://www.spire.com/spirepedia/satellite-ais. [Accessed on: 2019-01-29].

[184] Spire Global Inc. Spire AirSafe. [Online], dec 2018. URL https://spire.com/aviation/aviation-pricing/. [Accessed on: 2020-05-05].

[185] Spire Global Inc. Spire Global and Airbus Partner to Deliver Global Aircraft Surveillance Data. [Online], mar 2018. URL https://spire.com/company/insights/news/spire-global-and-airbus-partner-deliver-global-air/. [Accessed on: 2018-12-20].

[186] Spire Global Inc. Careers. [Online], 2018. URL https://spire.com/careers/. [Accessed on: 2018-12-22].

[187] Spire Global Inc. Company. [Online], 2018. URL https://spire.com/company/. [Accessed on: 2018-12-22].

[188] Spire Global Inc. Culture. [Online], 2018. URL https://spire.com/careers/culture/. [Accessed on: 2018-12-22].

[189] Spire Global Inc. Spire extends access to space with DHV Technology solar panel partnership. [Online], mar 2018. URL https://spire.com/company/insights/news/spire-extends-access-space-dhv-technology-solar-pa/. [Accessed on: 2018-12-20].

[190] Spire Global Inc. Spire Data Catalogue for ESA Earthnet. [Online], nov 2018. URL https://in.spire.com/earthnet. [Accessed on: 2019-02-02].

[191] Spire Global Inc. Spire Data Now A Simple Integration for Existing Esri Customers. [Online], apr 2018. URL https://spire.com/company/insights/news/spire-data-now-simple-integration-existing-esri-cu/. [Accessed on: 2018-12-20].

[192] Spire Global Inc. Spire Global and INDMEX Aviation Sign Letter of Intent. [Online], mar 2018. URL https://spire.com/company/insights/news/spire-global-and-indmex-aviation-sign-letter-inten/. [Accessed on: 2018-12-20].

[193] Spire Global Inc. Spirepedia: Lemur. [Online], jul 2018. URL https://www.spire.com/spirepedia/lemur. [Accessed on: 2019-01-29].

[194] Spire Global Inc. Solutions: Aviation. [Online], 2018. URL https://www.spire.com/en/solutions/aviation. [Accessed on: 2019-02-01].

[195] Spire Global Inc. Solutions: Government and Military. [Online], 2018. URL https://www.spire.com/en/solutions/government-amp-military. [Accessed on: 2019-02-01].

[196] Spire Global Inc. Solutions: Meteorology. [Online], 2018. URL https://www.spire.com/en/solutions/meteorology. [Accessed on: 2019-02-01].

[197] Spire Global Inc. Solutions: Shipping and Maritime. [Online], 2018. URL https://www.spire.com/en/solutions/shipping-amp-maritime. [Accessed on: 2019-02-01].

[198] Spire Global Inc. Solutions: Supply Chain and Logistics. [Online], 2018. URL https://www.spire.com/en/solutions/supply-chain-amp-logistics. [Accessed on: 2019-02-01].

[199] Spire Global Inc. Team. [Online], 2018. URL https://spire.com/company/team/. [Accessed on: 2018-12-23].

[200] Spire Global Inc. UK Space Agency Backs Spire's Proposal to European Space Agency as Space Mission Provider. [Online], feb 2018. URL https://spire.com/company/insights/news/uk-space-agency-backs-spires-proposal-european-spa/. [Accessed on: 2018-12-20].

[201] Spire Global Inc. Visualization and GIS. [Online], 2018. URL https://spire.com/en/product-suite/visualization-and-gis. [Accessed on: 2019-04-29].

[202] Spire Global Inc. Spire Maritime. [Online], 2019. URL https://spire.com/maritime/maritime-pricing/. [Accessed on: 2020-05-05].

[203] Spire Global Inc. Spire OS: Orbital Services. [Online], 2019. URL https://www.spire.com/en/product-suite/orbital-services. [Accessed on: 2019-02-05].

[204] Spire Global Inc. Spire Stratos. [Online], 2019. URL https://spire.com/weather/. [Accessed on: 2020-05-05].

[205] O. Stjerngren and C. Elvind. Commissioned Research: GomSpace - Small satellites invade 'new space'. Technical report, Danske Bank A/S, Stockholm, Sweden, 2018.

[206] O. Stjerngren and C. Elvind. Commissioned Research: GomSpace - Cost cutting and focus on becoming cash flow positive. Technical Report February, Danske Bank A/S, Stockholm, Sweden, 2019.

[207] C. Stöcker, R. Bennett, F. Nex, M. Gerke, and J. Zevenbergen. Review of the current state of UAV regulations. *Remote Sensing*, 9(5):33–35, 2017. ISSN 20724292. doi: 10.3390/rs9050459.

[208] Trecasa. AISTECH SPACE, S.L. y TRACASA firman un MOU (Memorandum of Understanding). [Online], apr 2018. URL https://tracasa.es/aistech-space-s-l-y-tracasa-firman-un-mou-memorandum-of-understanding/. [Accessed on: 2019-12-02].

[209] A. P. Trishchenko, L. Garand, and L. D. Trichtchenko. Three-apogee 16-h highly elliptical orbit as optimal choice for continuous meteorological imaging of polar regions. *Journal of Atmospheric and Oceanic Technology*, 28(11):1407–1422, 2011. ISSN 07390572. doi: 10.1175/JTECH-D-11-00048.1.

[210] Union of Concerned Scientists. UCS Satellite Database. [Online], apr 2020. URL https://www.ucsusa.org/resources/satellite-database. [Accessed on: 2020-05-15].

[211] G. Valenzuela Ramos. Guillermo V. Ramos. [Online], 2019. URL https://www.linkedin.com/in/guillermo-v-ramos-a441a5116/. [Accessed on: 2019-11-22].

[212] S. van den Dries. Introducing Spire (Sense). [Online], jul 2018. URL https://www.linkedin.com/pulse/introducing-spire-sense-simon-van-den-dries/. [Accessed on: 2019-02-02].

[213] J. Van Wagenen. Spire Releases CubeSat - Based Flight Tracking Solution. [Online], dec 2016. URL https://www.satellitetoday.com/innovation/2016/12/06/spire-releases-cubesat-based-flight-tracking-solution/. [Accessed on: 2018-12-18].

[214] Via Galicia. 90 segundos con Aistech Space | ViaGalicia 4ª edición. [Video], dec 2017. URL https://youtu.be/nxrcsVRDwtc.

[215] J. Virgili Llop, P. C. Roberts, and Z. Hao. Aerodynamic attitude and orbit control capabilities of the ΔDSAT cubesat. *Advances in the Astronautical Sciences*, 151(January 2014):321–332, 2014. ISSN 00653438.

[216] J. Virgili Llop, P. C. Roberts, Z. Hao, L. Ramio Tomas, and V. Beauplet. Very Low Earth Orbit mission concepts for Earth Observation: Benefits and challenges. In *12th Reinventing Space Conference*, number January 2016, pages 1–18, 2014.

[217] J. Virgili Llop, P. C. E. Roberts, K. Palmer, S. Hobbs, and J. Kingston. Descending Sun-Synchronous Orbits with Aerodynamic Inclination Correction. *Journal of Guidance, Control, and Dynamics*, 38(5):831–842, 2015. ISSN 0731-5090. doi: 10.2514/1.G000183.

[218] S. M. Volz and T. Gallaudet. Commercial Weather Data Pilot Program. Technical report, Department of Commerce - National Oceanic and Atmosphere Administration, Washington, D.C., USA, 2018.

[219] R. Walker, L. León Pérez, and P. Koch. GOMX-4: The twin European mission for IOD purposes. In *32nd Annual AIAA/USU Conference on Small Satellite*, pages 1–10, Logan, Utah, USA, 2018. GomSpace ApS.

[220] G. Warwick. Spotlight on Bizjet-based Special Mission Aircraft. [Online], jan 2018. URL https://goo.gl/zhLftn. [Accessed on: 2018-10-02].

[221] T. Watts. Demise Observation Capsule (DOC) for re-entry science and safety. [Online], oct 2018. URL http://stcorp.nl/highlights/demise-observation-capsule-doc-re-entry-science-and-safety/. [Accessed on: 2019-07-22].

[222] T. Wekerle, J. B. Filho Pessoa, L. E. Vergueiro Loures da Costa, and L. Gonzaga Trabasso. Status and trends of smallsats and their launch vehicles - An up-to-date review. *Journal of Aerospace Technology and Management*, 9(3):269–286, 2017. ISSN 21759146. doi: 10.5028/jatm.v9i3.853.

[223] D. Werner. ESA-backed startup banking on inflation. [Online], sep 2016. URL http://www.spacenewsmag.com/feature/esa-backed-startup-banking-on-inflation/. [Accessed on: 2019-11-25].

[224] D. Whitford. Why Hedge Funds, Militaries, and NGOs All Want This Company's Satellites. *Inc.*, oct 2016. URL https://www.inc.com/magazine/201610/david-whitford/spire-peter-platzer-flying-objects.html.

[225] C. Williams and S. DelPozzo. A Different Approach: Vertical Integration in Satellite Manufacturing. [Online], 2019. URL https://www.spaceworks.aero/a-different-approach-vertical-integration-in-satellite-manufacturing/. [Accessed on: 2020-05-20].

[226] C. Williams and S. DelPozzo. SpaceWorks' 2020 Nano / Microsatellite Market Forecast, 10th Edition. Technical report, SpaceWorks Enterprises, Inc., Atlanta, USA, 2020.

[227] World Bank Group. What is the Blue Economy? [Online], jun 2017. URL http://www.worldbank.org/en/news/infographic/2017/06/06/blue-economy. [Accessed on: 2019-06-15].

[228] World Meteorological Organization. WMO OSCAR | List of all Satellites. [Online], 2018. URL https://www.wmo-sat.info/oscar/satellites. [Accessed on: 2018-12-08].

[229] Xerra. CSST AND SPIRE PARTNERSHIP – BRINGING AIS DATA TO THE PACIFIC. [Online], feb 2018. URL https://www.xerra.nz/2018/02/22/csst-and-spire-partnership-bringing-ais-data-to-the-pacific/. [Accessed on: 2019-05-02].

[230] R. K. Yin. *Case Study Research: Design and Methods*. Sage Publications, Inc., Thousand Oaks, CA, USA, 5th edition, 2014. ISBN 978-1-4522-4256-9.