GEOScan Executive Summary

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Dedicated to Emilio di Pasquale

1966 - 2020

Forever part of the SpaceTech2020 cohort.

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1 INTRODUCTION

The challenge of space debris is an ever-increasing problem that threatens the sustainability of space exploration and exploitation as orbital congestion increases exponentially. During the last six decades of incredible space exploration and advancements, humanity has generated an estimated 170 million debris objects of sizes larger than 1 mm. Because of the substantial orbital velocities involved, a 1 cm or larger object of the estimated 670.000 could disable a spacecraft. Yet, the current capabilities only allow regular tracking of about 28.600 of them. The idea of driving on the highway with a speed of about 4 – 8 km/s while being able to see only about 4% of the potentially dangerous objects around is not very compelling. Furthermore, any collision generates even more debris, and when improperly disposed of, derelict spacecraft or launcher stages drifting uncontrolled in Earth orbits represent a potential risk of self–explosion/ fragmentation. In the long run, this will increase the debris population in orbit, in a cascading, exponential manner, the so-called Kessler Syndrome, and aggravate the space environment problem.

In the GEO region, the problem seems less dramatic than in LEO for the time being, but it is experiencing a different phenomenon. The increase in mass over the years indicates a prelude to the future growth of the space debris population, threatening the integrity of the satellites and the continuity of the related provided services on the ground to millions of customers.

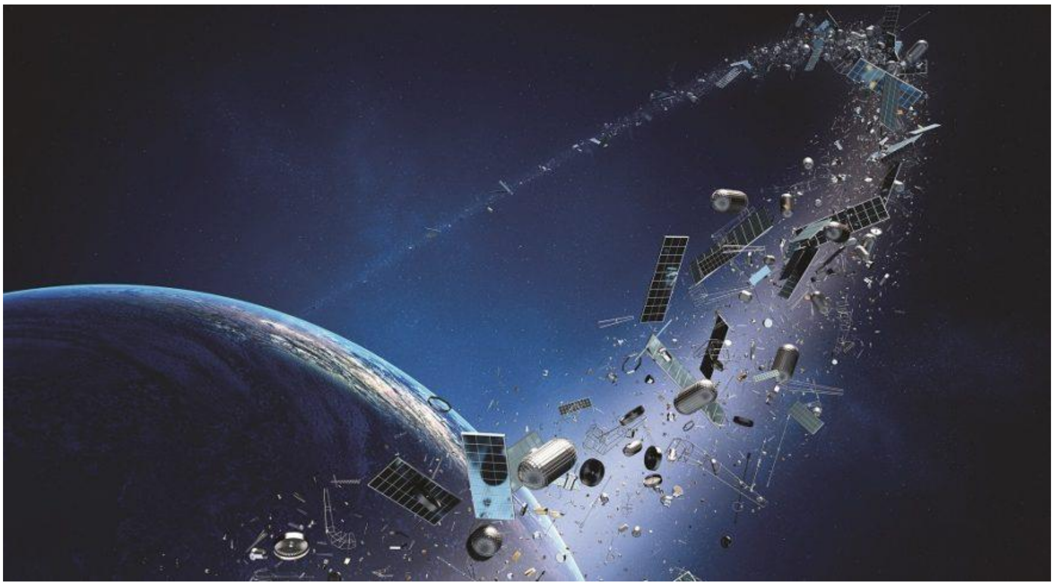


Figure 1-1 Artist impression of space debris in GEO (credit: SpaceNews.com).

Space agencies and, more specifically, satellite operators that own large spacecraft and costly constellations designed to survive the harsh space environment for 15 years are calling for better control of man-made objects that could cause unrecoverable damages to their spacecraft. They encourage initiatives to better understand the space debris population, obtain more accurate data on position and velocity, and finally better predict the orbit in the future. Different stakeholders express that this knowledge will, in turn, contribute to the safe use of the GEO region without losing too many resources in the processing of unverified debris avoidance alerts, unnecessary manoeuvres or interrupting the services provided to the customers.

Furthermore, there are currently limited ground-based capabilities to collect information about active spacecraft and anomaly detection or damage assessment because of the large distances involved. Ground-based capabilities mainly rely on the on-board sensors, which are of limited use if there is no communication spacecraft. Several stakeholders have expressed the desire to obtain additional information on the objects in space to support the baseline signature and supporting these possible additional services.

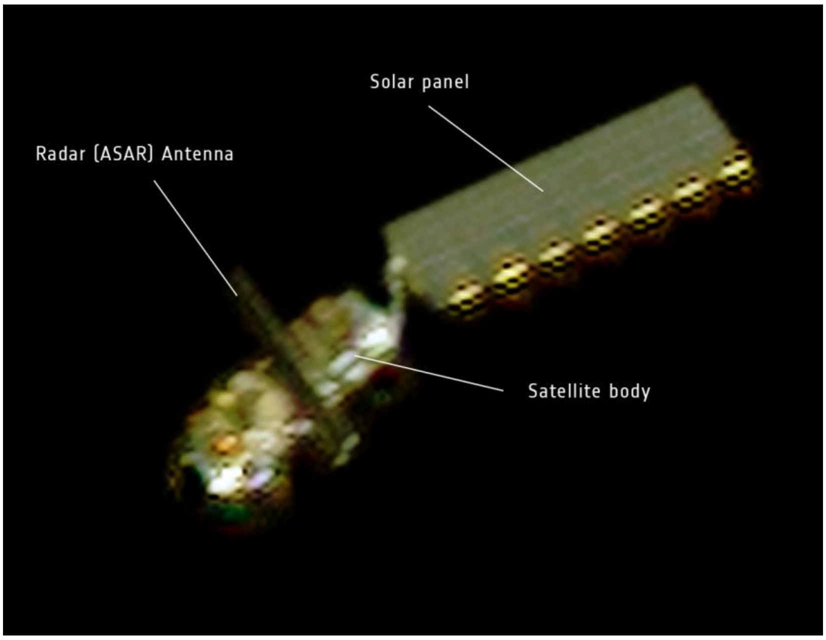


Figure 1-2 Image of Envisat taken by Pleiades satellite from LEO orbit (credit: ESA).

The man-made space environment problem of space debris has analogies to environmental problems, like global warming. For many years they seem elusive, the risk is underestimated, and very few initiatives are taken to address them. Yet, they evolve exponentially, affecting everyone. Solutions require global coordination, early start, long-term commitment, and serious investments. Lastly, since commercial benefits are not evident, private companies are reluctant to invest, and the global community relies on government-funded initiatives that are scarce and less agile. If the lessons learned from the Earth's environmental problems are used, there is hope that the space environment problem will be tackled more effectively.

NAVIR is dedicated to space sustainability. Its mission is to make the GEO region safer and accessible for all space assets by minimising their risk of collision, reducing the cost of operations and raising awareness for a clean space environment. This awareness helps to change the way we think, create missions and operate them in the future.

NAVIR will offer the best and most accurate commercial Space Situational Awareness (SSA) services in GEO with its **GEOScan** fleet of 17 satellites. NAVIR is reinventing the market, being the first company with an SSA space segment in GEO, and delivering the highest precision, commercially available products and services on:

Number	Product	Services
1	Detect & Track	Tracking and ephemeris data of objects smaller than currently possible, Covariance information, correlation and conjunction alerts.
2	Characterise	Behaviour characterisation of functional spacecraft.
3	Inspect	On-demand spacecraft high-resolution imaging.

Table 1-1 GEOScan products and services.

NAVIR defines the future and safety of satellite operators by providing them with the required information that allows them to react faster and only when needed, minimising false alarms and thus the cost of operations for their customers.

This Executive Summary, which addresses the **GEOScan** Business Case and Technical Proposal, describes how NAVIR will monitor and characterise the space environment. Besides that, the ways in which NAVIR can increase the safety of operators' assets and reduce operators' costs in GEO are summarised and presented.

2 PROBLEM STATEMENT

2.1 What is the Problem?

The GEO region is critical for satellite operators due to its advantageous characteristics. Satellites in GEO constantly reside above one particular place over Earth. Telecommunications and weather monitoring satellite operators exploit this advantage well. The number of resident space objects (RSOs) is increasing considerably due to debris generated and the number of spacecraft launched to GEO during the last years.

Figure 2-1 Illustration of a rocket body explosion in space.

NAVIR's Market Survey Analysis (MSA)[1] found that the risk of a collision between the fleet of active spacecraft in GEO and a piece of debris of 1 cm or bigger is 21% per year. Since spacecraft in GEO are usually larger and more expensive than spacecraft in LEO, the financial risk of a collision could be more than $415 M per loss of spacecraft on average. This number includes both the replacement costs of the satellite and the lost revenue. The aggregated risk value (probability of an event multiplied by the cost of the event) is therefore almost $83 M per year for the entire GEO segment.

The great distance between the Earth's surface and the GEO region renders the current ground technology insufficient for precise and timely identification, tracking, and characterisation of RSOs. Especially smaller objects are not well observed and tracked, while they are considered a significant threat to damaging a satellite in case of a collision. Even though an object of 10 centimetres in size can severely damage or even destroy a satellite, current capabilities are mainly limited to observe objects above 1 meter in size in the GEO region. These aspects, together with the many false conjunction alerts, must be handled every year by operators. The difficulty in identifying the spacecraft's physical status in case of its malfunction or interruption of services is causing a direct impact on cost and effort to operators.

2.2 Who is Affected?

The importance of assets in the GEO region is tremendous. Most people's day-to-day life and business depend on satellite services from the GEO regime, even though most are unaware of this dependency. Examples of these services are broadcast television services, satellite communications worldwide, meteorological monitoring, and even some position and navigation services.

[1] NAVIR Market Survey Analysis, 2020, SpaceTech2020 Programme

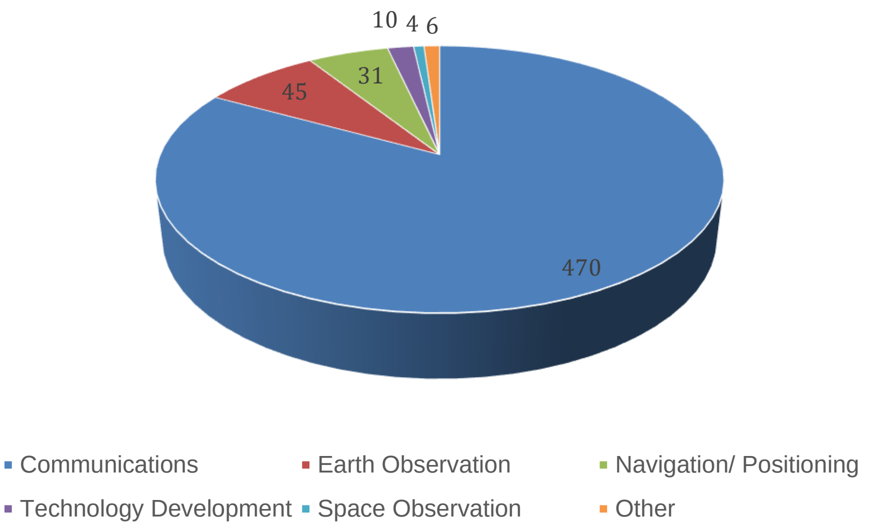


Figure 2-2 GEO satellite missions (Union of Concerned Scientists database Jan-2021).

Indirectly, most people on Earth benefit from a more secure GEO region to offer reliable services. Directly, we see a great benefit for satellite operators that own or operate satellites in or around GEO. Currently, objects of less than 1 meter in size are not well observed and tracked. The result is that operators only receive alerts for big objects, while smaller objects can still pose a considerable risk. The location precision and accuracy of objects are also insufficient, causing many false alerts and large covariance matrices. These many and false alerts force operators to make unnecessary satellite manoeuvres, diminishing their operational lifetime and causing significant. The fact that characteristics of objects are only partly known adds to this inaccuracy.

When operators place assets in the GEO region, the possibility to view a spacecraft is minimal, implying that operators have to solve problems in satellite operations with incomplete information and that direct detailed observation is not possible.

2.3 Current Cost/ Risk

There are estimated to be more than 4,500 satellites in space in the next decade, with a combined value above €125bn, of which more than €45bn will be in the GEO region. The €45bn value in GEO comprises over 450 functional satellites for commercial, governmental, and military use. They are valued at over €18bn for commercial and €21bn for military and government.

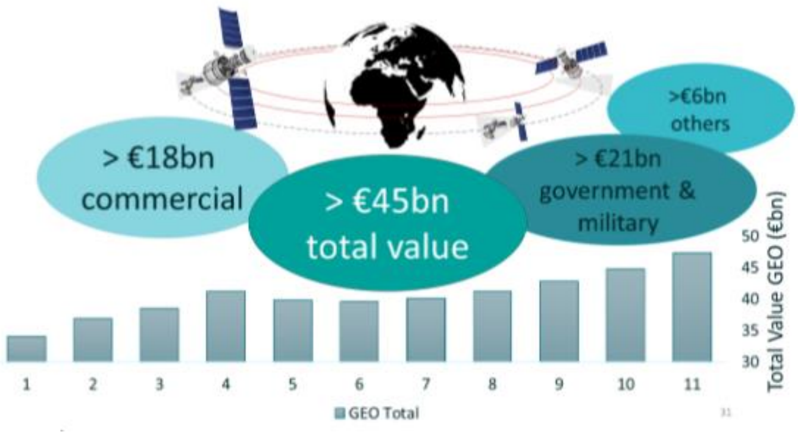


Figure 2-3 Total value of spacecraft in GEO per operator type.

Losing a single satellite in GEO can cost an operator on average around €108 M and as much as €415 M. This amount includes the launch and replacement of the satellite. These numbers are excluding potential loss of revenue and reputation if services become unavailable for users. There are over 330 commercial GEO satellites with a combined revenue estimate above €36 bn per year.

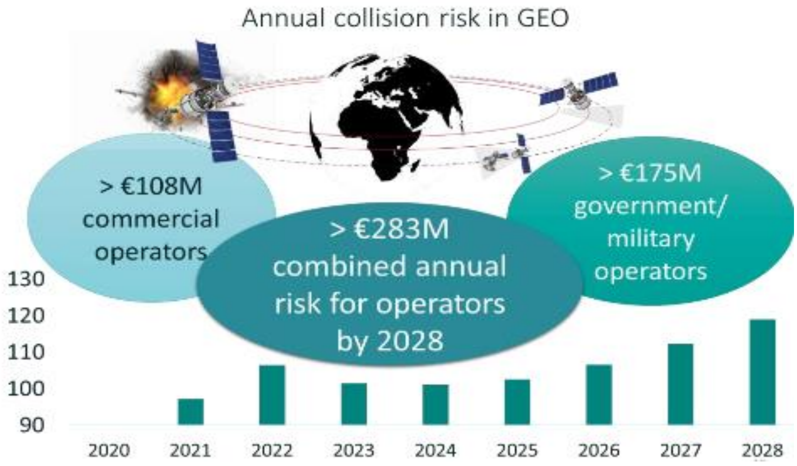


Figure 2-4 Annual collision risk in GEO per operator type.

We have assessed that the current annual value of commercial collision risks for GEO operators is €82 M per year, increasing to €230 M in the next decade. Of course, this estimation addresses collision risk and does not include potential revenue loss for satellite anomalies, survey, and damage inspection. It also excludes governmental aspects, such as replacement or augmentation of their current sensors, regulatory & compliance verification, and new opportunities such as mission surveys for active debris removal (ADR).

2.4 Existing Landscape

Current capabilities for Space Situational Awareness (SSA) and Space Domain Awareness (SDA) in GEO are somewhat limited because sensors are mainly optical and Earth-based with significant distances involved and affected due to weather and time-of-day restrictions. As a result, only objects greater than 40 cm are detected and regularly tracked.

Several customer needs that current commercial solutions cannot fully address are:

1. Provide accurate conjunction analysis;
2. Reduce the number of unnecessary manoeuvres;
3. Reduce operations workload;
4. Understand object behaviour and capabilities;
5. Detect changes in object behaviour and the physical form of objects in space;
6. Assess failure and damage visually.

An estimated 99% of current collision alerts are false alarms. These alerts still require analysis and assessment, using up a valuable workforce. On average, there are two avoidance manoeuvres per satellite per year. To reduce the false alarms and the subsequent unnecessary manoeuvres, significant improvement (in the order of factor 5) in the detection & tracking capability accuracy is necessary.

Operators and governmental organisations want to obtain as much information on objects and their satellites as possible, especially if there is a possible anomaly or change in behaviour. Currently, they are limited to deriving data mainly based on telemetry information from their satellites.

Knowing object characteristics such as their manoeuvring behaviour, flight attitude and shape, and the ability to detect changes from nominal behaviour enables support for the early detection of anomalies and threats.

These same operators and organisations also require more refined information when things go wrong or when they need to monitor critical activities. This required information includes, for example, the ability to capture detailed information about an object.

Company	Size	Accuracy	Price	System	Focus
CSpOC (USSPACE COM)	1m	TLE: Low	Free	Ground & Space	Institutional, Defence
EUSST	35cm (in 2028)	Medium	Free, only for member states	Ground	Institutional & Defence
Space Data Association (SDA)	Sharing of ephemeris only	High	Free, sharing on voluntary basis	n/a	Institutional, members only
ExoAnalytic Solutions	40cm (less after post-processing)	1-2.5 microrad	Tiered subscription	Ground	Commercial
NAVIR GEOSCAN	10cm (less after post processing)	High	Subscription & on demand	Space	Commercial

Table 2-1 NAVIR competitors analysis.

ExoAnalytic Solutions is considered one of the primary commercial competitors at this time. ExoAnalytic Solutions is well established, declaring the ability to detect up to 40 cm objects and with post-processing much smaller. Still, they have some limitations due to the use of primarily optical instruments, which are affected by distance, atmosphere, and cloud cover.

Current Space Domain Awareness providers rely on ground-based sensors, which have limited performance in the GEO regime. Some governmental organisations, such as the European Union Space

Surveillance and Tracking (EU-SST) program, target similar SSA objectives as **GEOScan.** EU-SST strives to detect objects up to ~35 cm by 2025 (vs 10 cm of GEOScan), and the US Combined Space Operations Centre (CSpOC) provides a free government-funded service based on a range of sources & sensors.

2.5 The Solution

The capabilities that would significantly enhance the situational awareness in the GEO region are the observability of smaller objects, improved accuracy of observations of all objects, the possibility to inspect spacecraft from up-close, and a timely warning of any changes in the behaviour of objects by characterising spacecraft regularly.

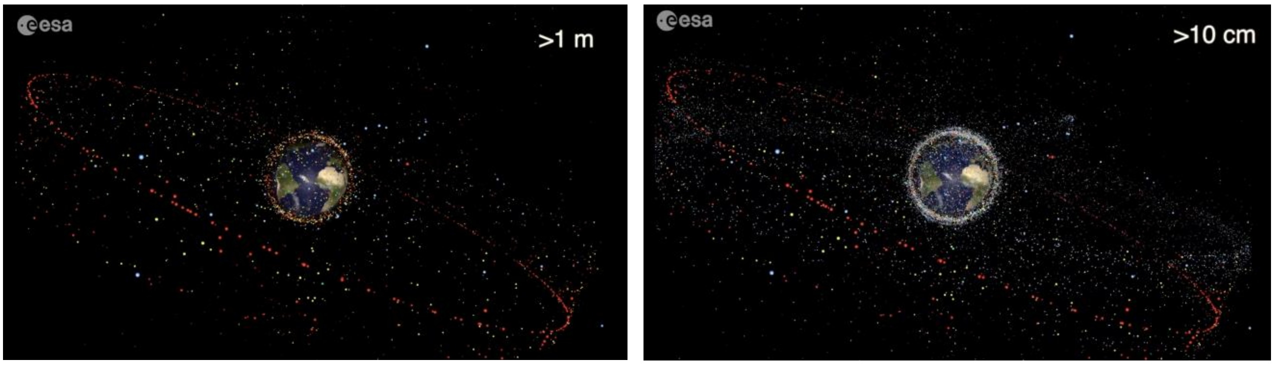


Figure 2-5 RSO objects larger than 1 m and 10 cm (Source: ESA).

To react proactively to threats, satellite operators need timely information on all objects that can threaten their spacecraft and not just on the big objects current capabilities are limited to. This information includes both a precise location but also an accurate propagation of the trajectory. The improved location precision and accuracy, better correlation possibilities and the resulting smaller covariance values diminish the number of false alerts. This means that all the operators' efforts can be directed to more probable threats and not be lost on false alerts. Furthermore, when operators receive timely warnings whenever their spacecraft behaves erratically, they can react faster to impending problems. Lastly, the possibility to inspect their satellite can provide a swift and accurate determination of the root cause of problems they encounter.

GEOScan offers three different services with unique characteristics and features to provide a complete, flexible and customisable solution. The three services are called DETECT & TRACK, CHARACTERISE and INSPECT and are graphically represented in the following image.

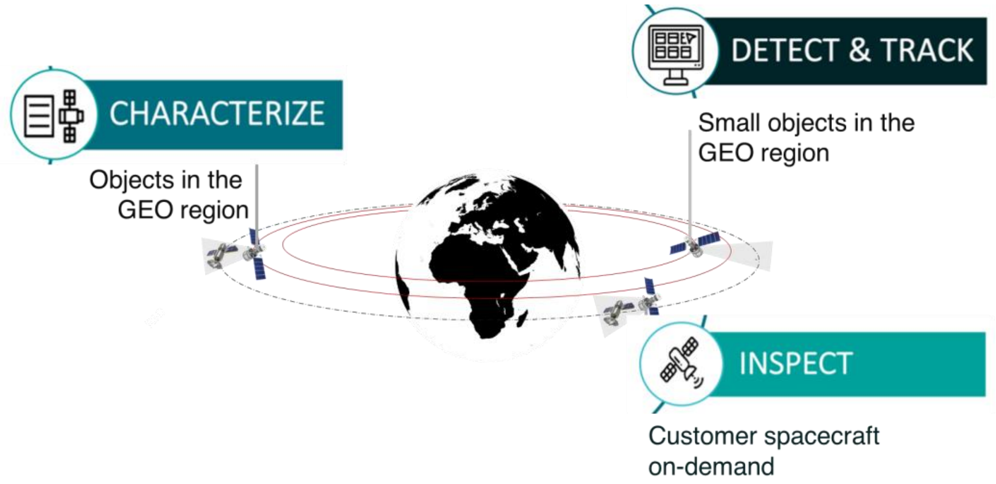


Figure 2-6 **GEOScan** services.

2.5.1 DETECT & TRACK

The DETECT & TRACK service provides operators with conjunction analysis services formed by Consultative Committee for Space Data Systems (CCSDS) Conjunction Data Messages (CDM) and mitigation assessment reports for customer satellites at regular intervals or on-demand.

Whenever **GEOScan** detects potential conjunction between the customer's spacecraft and an RSO, NAVIR alerts the customer. This alert includes all observed and derived characteristics of the objects involved.

This service can also provide an ephemeris report on specific operators' spacecraft. The information contained in this report is updated at least every 24 hours for active spacecraft and every 48 hours for other objects.

DETECT & TRACK enhances operators' knowledge on RSOs, capturing information on objects with a size equal to or greater than 10 cm and up to 15° inclination orbiting or crossing the GEO ring. Furthermore, it reduces the number of false conjunction alerts that operators have to face every year, thus reducing the required cost and human resources for satellite conjunction avoidance maneuvres.

2.5.2 CHARACTERISE

The CHARACTERIZE service provides a unique capability that allows customers to characterise the behaviour of functional spacecraft based on different accurate measurements such as orbital manoeuvring, the attitude of the satellite, the tumbling rate of the satellite about three axes, a size estimate, the emissivity, and an optical signature. These elements are specifically qualified to provide object identification analysis, proof of life, change detection, and alert for anomalous behaviour.

CHARACTERIZE can revisit objects at least every 30 days. Some characterisation components are based on information from the spacecraft in the DETECT & TRACK orbit and can be updated more frequently. The service includes an update of the report when new information is available.

CHARACTERISE improves the current information to assist customers in identifying changes and anomalies in spacecraft behaviour faster and with more certainty. It can also support other activities, such as improving models for conjunction avoidance and the identification and correlation of spacecraft. This information is interesting for commercial operators and governmental actors. Having this data and the behaviour over time enables an improved understanding of objects, their capabilities, activities, and possible threats.

2.5.3 INSPECT

The INSPECT service offers on-demand, high-resolution panchromatic images of customer spacecraft operating in the GEO region and the possibility to obtain an analysis inspection report based on the acquired images, if requested.

The images have a spatial resolution of up to 20 cm, and the response time is 48 hours or less up to 90% of the time. NAVIR delivers the acquired images securely in the format requested by the customer and facilitates an easy transfer.

INSPECT improves the knowledge about operators' in-orbit assets by detecting physical anomalies in case of contingencies. This service facilitates the root cause investigation and analysis, reducing the cost of the relevant investigation and helps to limit the service interruption duration.

3 TECHNICAL SOLUTION

3.1 Key Performance Parameters

The following table provides a summary of the most important system goals and objectives as defined for **GEOScan**:

KPP Title	KPP Description
Size	Detect RSOs of size > 10 cm anywhere in the GEO region.
Periodicity	Observe >90% of all registered RSOs in the company repository every 48 hours.
Change detection	Observe all active spacecraft in GEO every 24 hours.
Characterisation	Obtain size and shape information on all active spacecraft in GEO with an accuracy of +/- 2 m.
Resolution	Upon request, obtain optical images of spacecraft in GEO with a spatial object resolution of 20 cm.

Table 3-1 Key Performance Parameters.

3.2 Mission Overview

GEOScan satellites are of the SmallSat (< 500 kg of mass) class. Each satellite employs an optical telescope with state-of-the-art components to provide SDA services enumerated in the latter part of the proposal. The data from the satellites is sent to NAVIR's Mission Control Centre (MCC) via commercial ground stations. In addition to performing monitoring and control of the satellite, the MCC includes dedicated software and algorithms to process the satellite data, correlate it with known objects in the **GEOScan** master repository, propagate the objects' trajectories based on an incorporated perturbation model and assess the level of accuracy of the data and potential collisions. Other dedicated software is provided to support the user interface and exchange the data in a secure, user-friendly manner. The users interact with the system mainly via an internet-based application that ultimately interfaces with the software managed by the MCC. NAVIR builds the **GEOScan** satellites primarily from Commercial-of-the-Shelf (COTS) and high Technological Readiness Level (TRL) components.

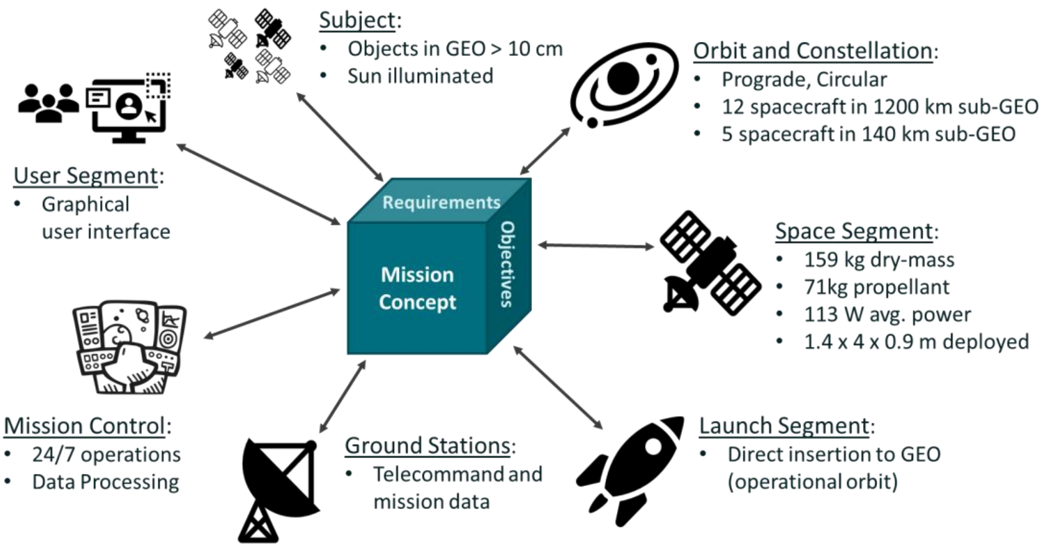


Figure 3-1 GEOScan mission overview.

3.3 End-to-End description

NAVIR will offer the best and most accurate commercial SSA services in GEO with its **GEOScan** fleet of 17 satellites. NAVIR is reinventing the market, being the first commercial company with a GEO-focussed SSA space segment. NAVIR leads the GEO market by delivering the highest precision, commercially available products and services described in Section 2.5.

NAVIR generates an exclusive RSO repository based on its superior raw and processed data while enhancing the existing public data. NAVIR defines the future and safety of satellite operators by allowing them to react faster and only when needed, minimising false alarms and thus the cost of operations for its customers. The added value of the **GEOScan** system is visible in the following figures.

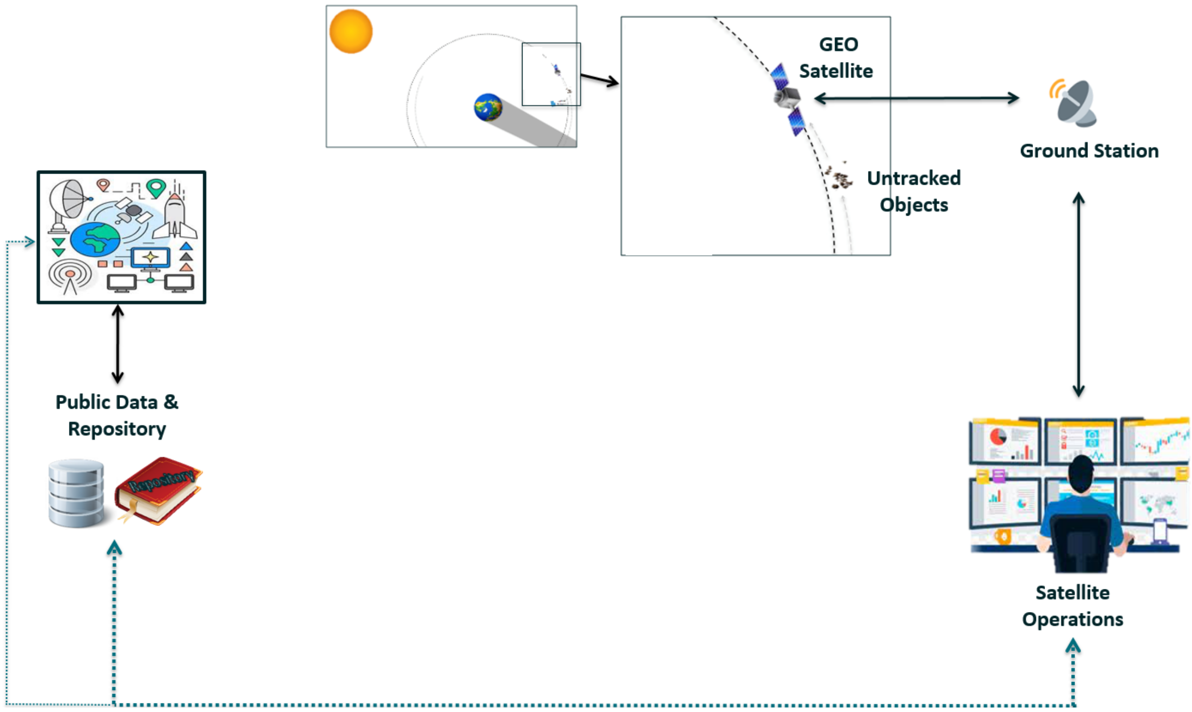


Figure 3-2 As-is situation before GEOScan system implementation.

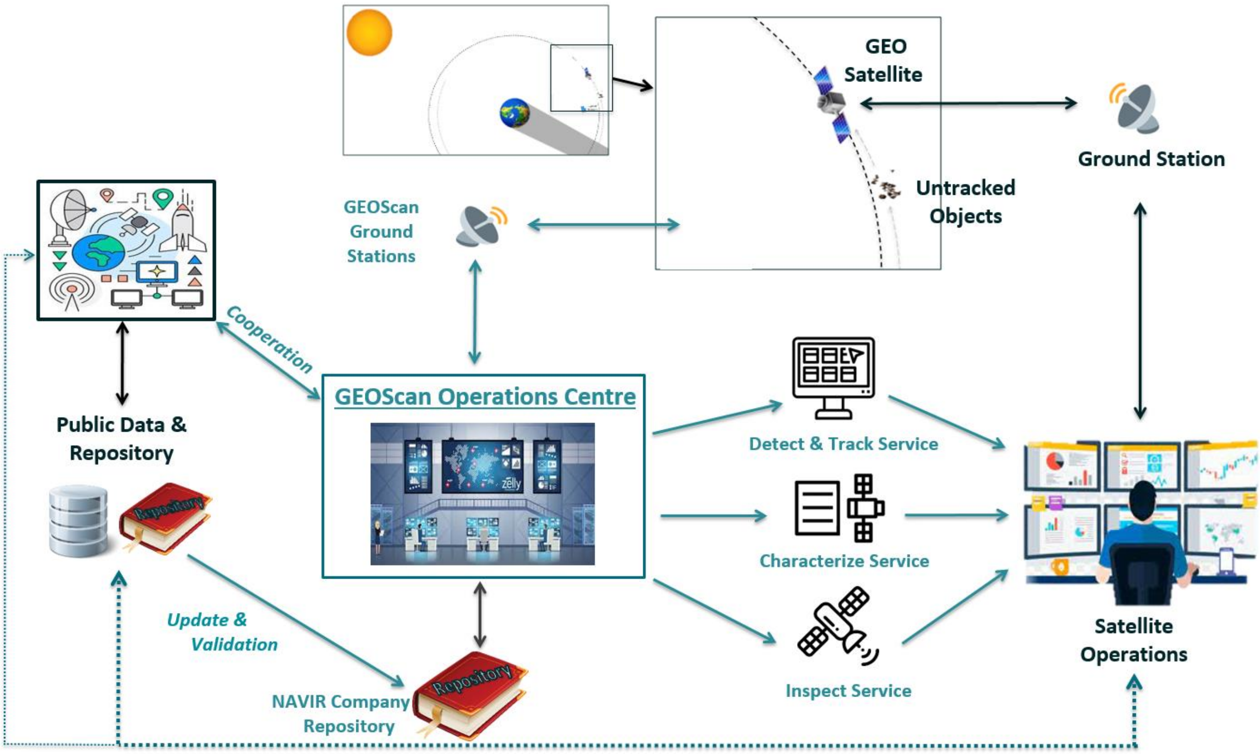


Figure 3-3 To-be situation after GEOScan system implementation.

3.4 Concept of Operations

GEOScan addresses the physical limitations experienced by the current ground-based service providers by offering a space-based solution. This solution incorporates a **Space Segment** arranged in a constellation of 17 satellites of the SmallSat class placed into two orbits. The orbits are selected to maximise the effectiveness for regular detection and tracking of GEO objects of 10 cm and larger and enable the capture of distinguishing features of the monitored objects (characterisation information) and high-resolution imaging. **GEOScan** uses optical telescopes to observe these objects.

The satellites are electrically powered using solar arrays, and they carry chemical propulsion to manoeuvre for inspections within the required timeframe. The interface to the **Ground Segment** utilises high bandwidth radio frequency connections with ground stations that communicate centrally with the **GEOScan** Mission Control Centre.

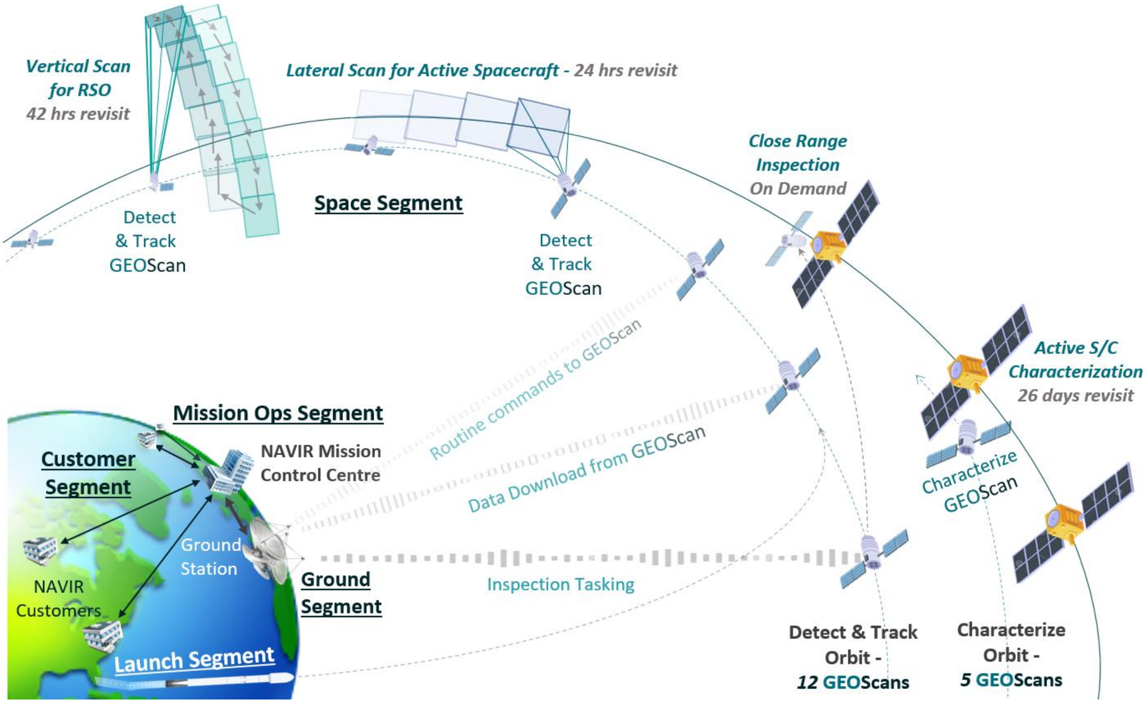


Figure 3-4 **GEOScan** ConOPS.

3.4.1 Orbit and Constellation

The **GEOScan** orbits are chosen based on a careful trade-off between the system's capabilities, the required revisit times, and the cost of the total constellation. A key consideration is an assumption that a larger payload results in a larger and more expensive satellite, but a smaller payload results in the need to be closer to the objects so that more spacecraft are needed in the total constellation to meet the revisit requirements.

After setting up a model that considered all factors for assessing the obtained signal, such as payload parameters, distance, size, albedo, Sun phase angle, integration time, and various background contributions, feasible mission orbits that fulfil the measurement requirements of the individual services were identified. Two orbits are chosen to perform the mission to meet the different requirements of the DETECT & TRACK, CHARACTERISE, and INSPECT missions. The DETECT & TRACK orbit is located 1200 km below GEO and ensures a revisit time of fewer than 48 hours with a total of 12 spacecraft. The spacecraft in this orbit can also accommodate the INSPECT mission requirements by including a chemical propulsion system to manoeuvre to the inspection orbit of 14 km below GEO.

The second orbit, intended for detailed characterisation, is located 140 km from GEO and provides a more precise image of GEO objects. Our chosen optical payload of 15 cm aperture, 3° Field-of-View, and a 16 Megapixel detector results in an image resolution of 2 m. Five spacecraft are needed in this CHARACTERIZE orbit to accomplish a revisit time of fewer than 30 days.

3.4.2 Observation Strategy

As visible in Figure 3-4, **GEOScan** operations are based around a series of comprehensive scanning patterns to ensure coverage, a sufficient integration time and the required revisited observation of objects. A series of vertical scanning cycles swipes vertical sections of the GEO environment to detect and track small RSOs with a 42-hour revisit, covering all orbital inclinations from 0° up to a limit of 15°. This is followed by a lateral scanning cycle to observe active spacecraft located on the

GEO ring with a revisit time of 24 hours. Subsequently, objects of interest and new objects that require more frequent observations for initial orbit determination and cataloguing are reobserved on-demand at frequent intervals. Observation data is then transmitted to the ground station via the data link.

3.5 Environment

Since the **GEOScan** orbits are located 1200 km and 140 km below GEO, respectively, this means they are located within the outer part of the outer Van Allen radiation belt. As such, they will accumulate total ionising radiation dose exceeding the values expected for a GEO mission. For the planned 10-year lifetime, the total ionising dose accumulated will range between 20 krad up to potentially 100 krad, depending on the location of the components on the spacecraft. Therefore, sufficient shielding must be accounted for to protect susceptible and critical components, particularly the system electronics.

3.6 Space Segment

3.6.1 Space Segment Design Philosophy and Overview

The **GEOScan** Space Segment chosen architecture approach is a common satellite bus and payload design to save on development and procurement costs. The system uses as much as possible off-the-shelf and qualified radiation-hardened equipment. It is designed with low complexity and high robustness in mind (equipment redundancy), and intelligence is added to minimise ground involvement for operations. A graphical overview of the space segment physical architecture and key characteristics is provided in Figure 3-5. A brief technical description of the payload and the main bus subsystems is provided in the following sections.

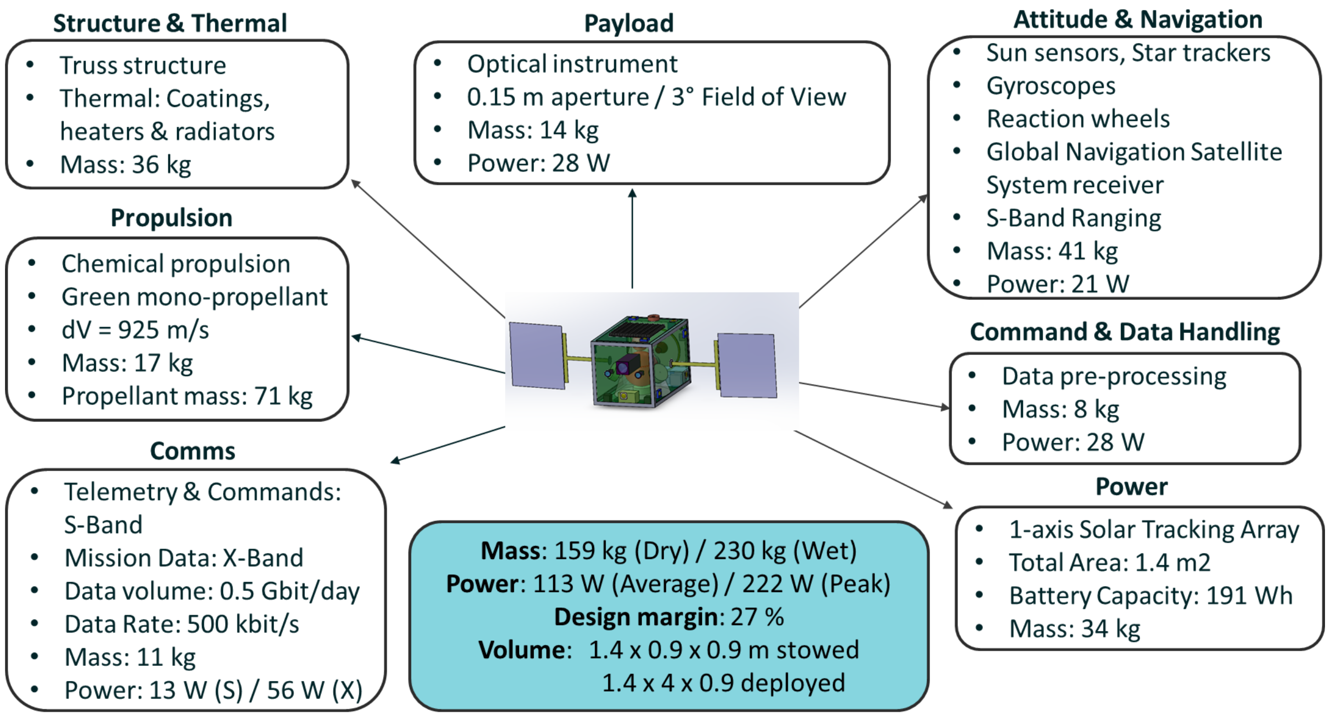


Figure 3-5 Space segment overview.

3.6.2 Payload: Optical Telescope

The main mission payload is an optical telescope capturing panchromatic images. The design strategy is to keep the aperture diameter small and achieve the required SNR and optical resolution by locating the spacecraft in orbit sufficiently close to the RSOs of interest. In this way, the cost of the payload and the size of the bus are kept low. A minimum aperture diameter of 15 cm is selected after a trade-off analysis between payload size, space segment cost and the number of required spacecraft to meet the key requirements of SNR for detection and tracking, optical resolution and revisit time. The instrument has a fixed Field of Regard, equal to its Field of View.

The leading system requirement for the detection and tracking is the SNR > 5 (for RSOs of > 10 cm of 0.1 albedo at 70 deg maximum phase angle) to allow for a sufficiently strong signal, the pixel size in space of < 80 m for accurate object orbit determination and low covariance, the large enough FoV of 3 to 6 deg to allow for sufficient coverage per image and the optical resolution. Derived requirements are sensor dimensions and pixel size, sensor technology and quantum efficiency.

Characteristic	Value
Number of Bands	1 (Panchromatic)
Wavelength	400 – 900 nm
SNR	> 5
Aperture	≥ 15 cm
Field of View	3 degrees
Sensor Type	CMOS
Sensor Quantum Efficiency	> 0.7
Pixel size	9 um
Mass	< 15 kg (13.5 kg baseline)
Power	< 40 W (28 W baseline)
Lifetime	> 10 years in GEO
Radiation Tolerance	> 80 krad

Table 3-2 Payload requirements.

The optical instrument will be procured and developed with an established manufacturer since an instrument that meets all requirements has not yet been identified after a market search. The payload will be based on existing designs of a TRL of six or more to keep development cost and risk low. A sizing by analogy is used to estimate the mass and power required for spacecraft sizing purposes. Several instruments of similar characteristics have been analysed in terms of their mass and power. A regressing model is fitted and then used to derive the payload mass and power estimates. A 30% margin is added on top.

The images are pre-processed on board, compressed, and only the pixels of interest are downlinked for further processing on the ground.

A summary of the key requirements and selected baseline of the instrument is shown in Table 3-2.

3.6.3 Satellite Bus

3.6.3.1 Attitude Determination and Control Subsystem (ADCS)

The **GEOScan** space segment must meet demanding requirements in terms of performance and robustness to deliver high-quality products to the end-users. Suppose those requirements drive many aspects of the payload, including the optical properties of the telescope and the selection of the CCD detector. In that case, they also drive the spacecraft attitude determination and control subsystem (ADCS) design for **pointing accuracy and stability**. The sensors, actuators and control algorithms are selected and sized to meet those driving requirements and ensure that the payload benefits from an optimal environment to perform its tasks. Indeed, the payload is fixed to the spacecraft body, and the scanning of the sky to detect and track objects is performed by successive changes of the spacecraft attitude.

Characteristic	Value
Pointing accuracy	Better than 72 arcseconds (0.02 deg)
Rate requirements (slew)	1.5 deg/s
Mass	40.5 kg
Power (avg)	21.3 W

Table 3-3 ADCS main characteristics.

The spacecraft attitude is determined by a star tracker, complemented by an accurate fibre-optic gyroscope. The **star tracker** measures the angular rate of the 3-axis with high accuracy but requires the support of a **gyroscope** to cope with possible reduced performance when the spacecraft attitude is changing quickly, which may occur during the scanning of the sky. A **sun sensor** is also added to the design to determine the Sun vector and participate in the attitude determination during the safe mode. Attitude control is performed by four hot redundant reaction wheels, which are offloaded by the propulsion subsystem. The **reaction wheels** are organised in a tetrahedral configuration, which can cope with one-wheel failure without impacting the mission.

The orbit determination of the spacecraft is achieved by ground using the traditional RF ranging method (S-band ranging), which require several ground stations and several observations. The AOCS is equipped with a **GNSS receiver** of the latest generation and specifically designed to receive the very low navigation signals at the geostationary orbit. Using GNSS, the spacecraft can rely on an accurate determination of its position and velocity and access the navigation constellation system time. The spacecraft does not need to embark a complex and expensive clock and can still very accurately synchronise the various subsystems and time tag the on-board events, including the observations made during detect and track and the imaging during the inspections.

3.6.3.2 Data Handling Subsystem (DHS)

The data handling on the spacecraft is performed by a Command and Data Management Unit (CDMU) based on a state-of-the-art power architecture with two e500Core processors capable of processing 3600 drhystone million instructions per second (DMIPS) and 1600 million of floating-point instructions per second (MFLOPS). The processing power is needed to run the on-board data handling software, including the ADCS software, and perform the data reduction of the mission data. This architecture is fully redundant and is considered the best solution due to its high processing power and compact design specifically developed to equip spacecraft constellations. The mission data is transferred from the payload to the CDMU via a SpaceWire communication bus, which provides a high data rate, and then stored on-board in a memory module provided by the CDMU. All TM/TC and mission data communication to and from the spacecraft is managed by the CDMU via the S-band and the X-band communication units. Spacecraft telemetry monitoring is implemented to report the spacecraft data handling functionalities, internal communications and provide on-board memory access to the ground.

The subsystem implements the Fault Detection Isolation and Recovery (FDIR) functionality in hardware (reconfiguration module) and software to handle failure at the lowest level. The principle is that the spacecraft design shall cope with one failure with minimum impact on the mission. The subsystem is closely linked with the Electrical Power Subsystem and can switch off units as needed in case of limited power available or in case of unit failure.

3.6.3.3 Electrical Power Subsystem

The power required for mission operations is delivered by two solar panels, one on each side of the spacecraft. The solar panels will have a single degree of freedom rotation mechanism, which means they can rotate around one axis to track the sun. Due to the complex scanning pattern, direct sun pointing at all times would put a lot of stress on the ADCS system. The solar arrays have been oversized to accommodate up to 45 degrees of solar aspect angle to reduce the attitude change

Characteristic	Value
Expected average power	113 W
Expected peak power	222 W for 15 min
Expected maximum solar aspect angle	45 degrees
Number of solar arrays	2
Rotation Mechanism	Single degree of freedom
Total solar array area	1.4 m^2
Battery capacity	191 Wh

Table 3-4 EPS main characteristics.

requirements. This configuration also alleviates the need for a more complex and expensive 2-degree of freedom system.

The battery stores and supplies power to the relevant systems when more power is needed than can be generated by the solar array. This occurs, for example, during peak power requests or when the solar panels do not generate power, i.e., at spacecraft initialisation when the solar panels are not yet deployed and during eclipses.

3.6.3.4 Communication Subsystem

The communication subsystem of each **GEOScan** spacecraft is divided into two different parts. The first one consists of the communication between the spacecraft and the ground stations. **GEOScan** spacecraft receive commands via an S-band link from the ground stations. These commands will generate an instruction to the spacecraft to perform a new observation pattern, change its attitude, correct a fault, operate a mechanism or other functions. The **GEOScan** spacecraft transmit telemetry data to the ground station with also an S-band link. This data is used to confirm that the instructions have been carried out and inform about the different subsystems' status in the spacecraft. A separate X-band link is used to communicate the payload data with the ground stations.

Characteristic	Value
S-band uplink data rate	20 kbps
S-band downlink data rate	100 kbps
X-band downlink data rate	400 kbps
6 S-band patch antennas gain	5 dBi
S-band transmitter output power	4 W
2 X-band 4x4 patch array antenna gain	16 dBi
X-band transmitter output power	4 W

Table 3-5 Communication subsystem main

There are different COTS options available for mini satellites with flight heritage to develop the functions described above and meet the requirements of GEOScan. Examples are TESAT or Syrlinks for the transmitter and transponder and EnduroSat or Ruag for the antennas. For the S-band links, patch antennas located on each side of the spacecraft ensure omnidirectional coverage to and from the ground stations. Together with the antennas, an S-band transponder receives and transmits, demodulates and modulates, and decodes and encodes the data. 4x4 patch array antennas, located at the nadir side of the spacecraft, are used for the X-band link. The ADCS subsystem performs the antenna pointing. An X-band transmitter, connected to the antenna, encodes, modulates and transmits the data.

After performing the corresponding link budget calculations, the characteristics mentioned in Table 3-5, together with the characteristics of the ground station network described in 3.8.1, ensure a budget link margin higher than 3dB, providing a reliable and robust link for adequate communication between **GEOScan** and the ground stations.

The second function of the communication subsystem is ranging, using the S-band transponder described above. **GEOScan** spacecraft demodulate the ranging signal contained in the uplink and re-modulate it onto the downlink. In this way, the return propagation time, the distance between the ground station and the satellite can be estimated.

3.6.3.5 Thermal Subsystem

There are large temperature changes in space, depending on whether the satellite is in sunlight or the Earth shadow during eclipse. The thermal subsystem maintains the payload and subsystems within a safe temperature range. The spacecraft will be exposed to the sun rays 95% of the time, allowing it to maintain a safe temperature. Thermal radiators are fitted to control excess thermal loads when the large faces of the satellite are normal to the sun and help manage excess heat when systems are operated all at once. The spacecraft may find itself eclipsed from the sun by the Earth for up to 5% of its orbit at certain times of the year. In this situation, the internal temperature will drop, and electric heaters will generate heat to prevent the temperature from falling below the minimum operational limit. The spacecraft is coated with a paint designed to allow for an optimum ratio of external heat absorbance to internal heat radiation to avoid using its active thermal system, such as heaters, during normal operational environmental conditions.

3.6.3.6 Propulsion Subsystem

The rationale behind the design of the propulsion system is the assumption that the space element will be directly injected into the sub-GEO orbit. This decision is further explained in section 3.7 - Launch Strategy.

Additionally, two majors constraints are driven the design process:
- The need for orbit modifications to perform inspections; and
- The attitude control and station keeping.

The propulsion system must be able to cope with all planned manoeuvres. Several trade-offs resulted in the selection of Chemical Propulsion, specifically, Monopropellant. Simplicity, high reliability, and reduced volume required when compared with the bipropellant are the key points in this decision.

Based on the selection of Chemical Propulsion, Stakeholders posed an additional requirement to the type of propellant. **GEOScan** must use Green Propellant. There are several benefits when using Green propellants. This mitigates the cost and risk associated with the transport and storage, clean-up of accidental releases, and human exposure to traditional propellants. They have lower toxicity and are less prone to ignition due to mishandling than traditional propellants.

The result of this design process is a Propulsion System with two tanks, one propellant and one pressurant tank, occupying a high volume of the space element.

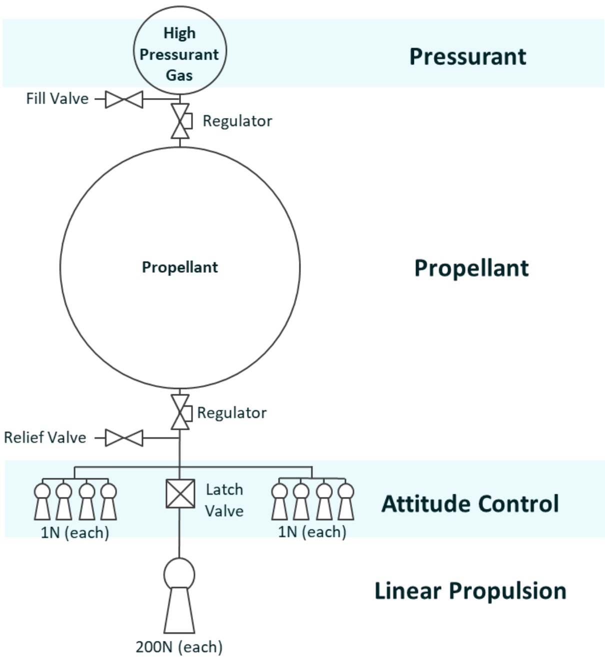


Figure 3-6 Propulsion system diagram.

The final system is provided with 8 ADCS thrusters in pairs at 4 locations pointing in different directions. Each thruster provides a thrust of a maximum of 1 N. This will allow **GEOScan** to provide enough thrust for the 3-axis attitude control and desaturation of reaction wheels.

Additionally, manoeuvring to modify the orbit as part of **GEOScan** INSPECTION, i.e. an orbit modification from 1200 km sub-GEO to 14 km sub-GEO in less than three days, introduces a very demanding requirement on the propulsion system. This capability is fulfilled with one thruster of 200 N located at the back-side of the spacecraft. The maximum acceleration allowed when performing this manoeuvre does not exceed 0.5 g (m/s^2).

Finally, the propulsion system is sized to reposition all satellites in the constellation along the final operational orbit.

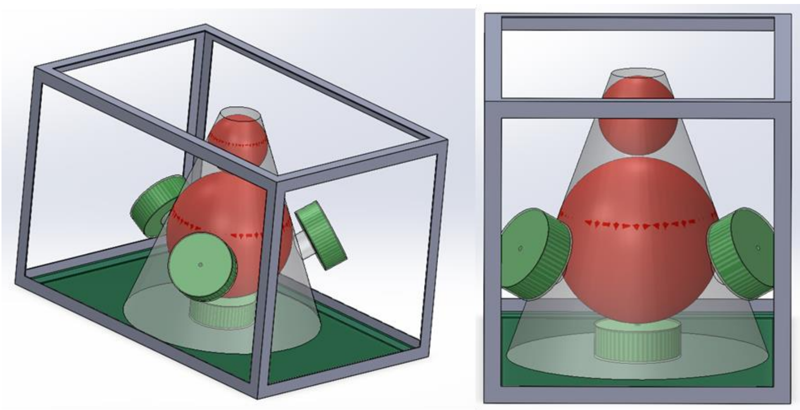


Figure 3-7 3D Model of pressurant and propellant tank.

3.6.3.7 Structure and Mechanisms

The Satellite Bus features a classic design with a rectangular shape. It is 1.4 m high with sides of 0.9m in length, forming a square base. The electronic and radiation-sensitive components are protected from the environment by a 5 cm thick electronic box, while the rest of the components are enclosed, along with the electronic box, in the outer shell of the spacecraft. The monocoque truss structure is made of an Aluminium Alloy with a truss on each edge supporting the rectangular panels also made of Aluminium alloy. The heavier components, such as the fuel tank, are supported by struts attached to the truss structure fittings, providing the attachment for the outer shell panels. The two small faces of the satellite host the payload and the star trackers on one side, and the thrusters, launch adapter and various communication antennas on the other side. The four large faces of the spacecraft provide attachment for the solar arrays' struts on the sides, the thermal radiators on the top and bottom faces, the GNSS receiving antennas and a sub-set of the communication antennas.

3.6.4 Spacecraft Conceptual Design

The space element is modelled in 3D and considers the different satellite subsystems. The next figures show an exploded, deployed and undeployed view of the satellite.

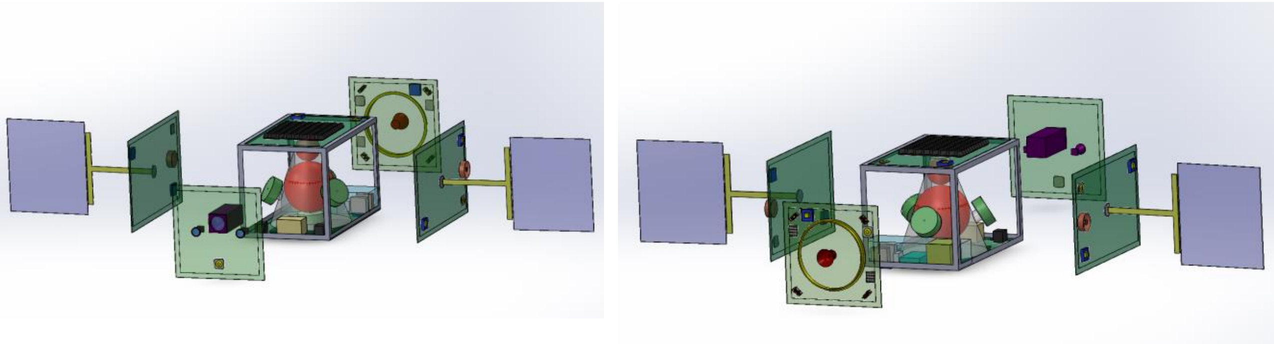


Figure 3-8 3D Model of the space element (exploded view).

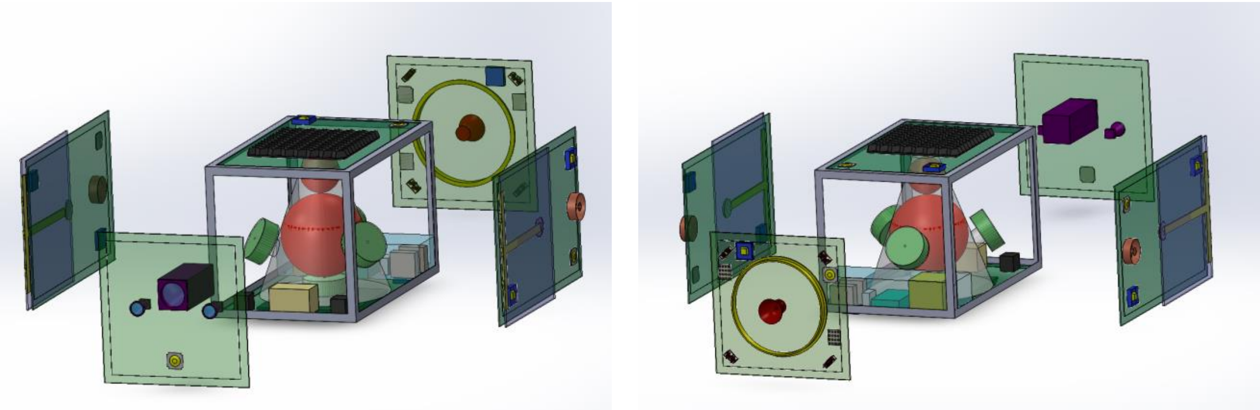


Figure 3-9 3D Model of the space element (exploded view).

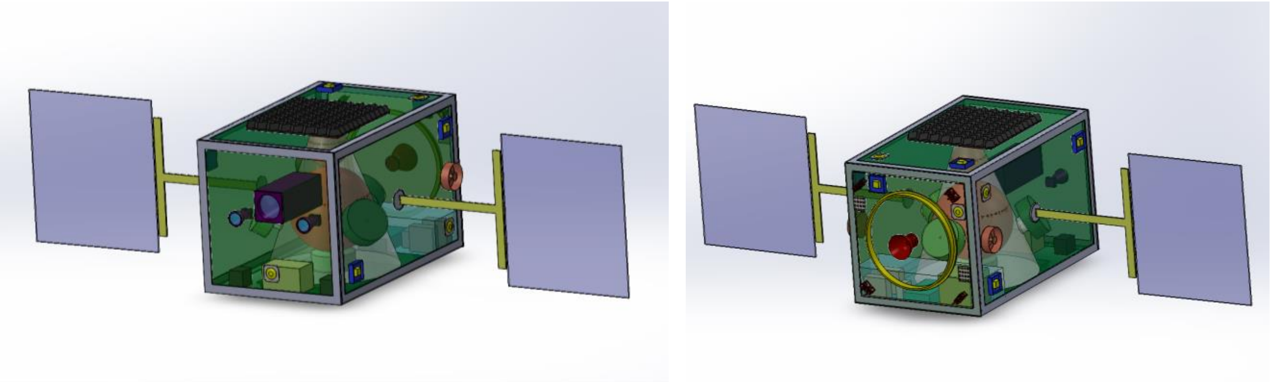


Figure 3-10 3D Model of the Space element (deployed view).

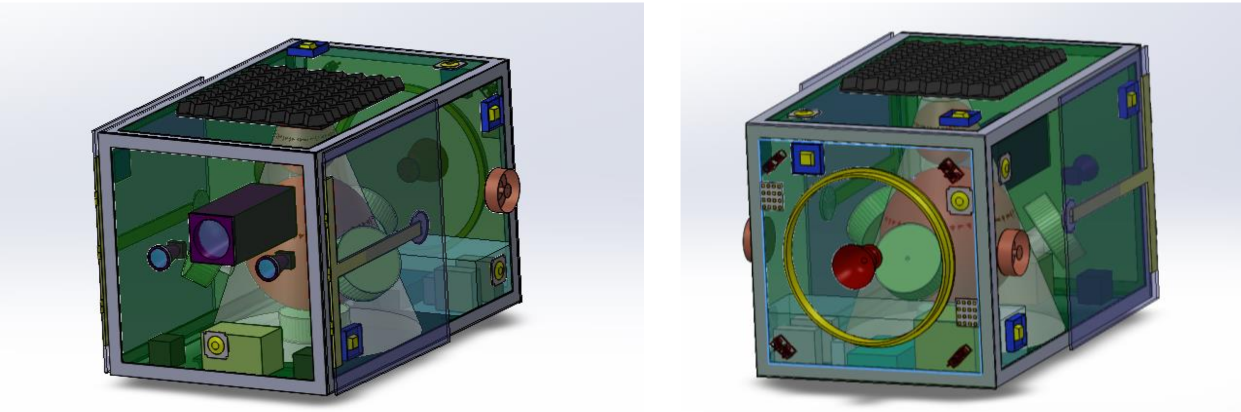


Figure 3-11 3D Model of the space element (stowed view).

3.7 Launch Strategy

The impact of the launch cost in the Business Model is carefully treated. As one of the highest contributing factors to the mission´s lifecycle cost, the launch strategy must provide an efficient deployment of **the GEOScan** constellation, considering the costs, risks and operational constraints.

The analysis of the constellation launch and deployment strategy is considering:
1) The evaluation of the injection and transfer strategy; and
2) The evaluation of dedicated, rideshare (Cluster Launches) or piggyback launches options.

For the evaluation of the injection and transfer strategy, it should be mentioned that the Geostationary Orbit could be accessed by: 1) direct injection or 2) using a transfer obit GTO to then circularise to the final operational orbit. As the launch strategy is affecting not one but 17 satellites, the increase of Delta-V and Mass was part of the initial assessment of the launch strategy.

SUBJECT	GTO	DIRECT INSERTION
Delta-V (m/s)	2 538	925
Wet Mass (kg)	450	230

Table 3-6 Delta-V and mass evaluation as part of the launch strategy.

Using a transfer orbit (GTO), the required Delta-V for every single satellite is penalised by an increase of approx. 1500 m/s. This represents an increase of the Wet Mass of two (2) times. When considering the full constellation of 17 satellites, the initial cost estimation shows savings whether a direct insertion is selected to reach the 1200 sub-GEO operational orbit.

SpaceX and Ariane were interviewed during the course of the analysis. As a result, the dedicated launcher and rideshare options were considered the most convenient for the mission. Rideshare would make **GEOScan** constellation´s deployment easier and phased, while a dedicated launch could reduce the cost associated with the launch.

Based on the capabilities of both Ariane 6.4 and Falcon Heavy, the full constellation of 17 spacecraft could be launched in a single launch. In both options, a kick stage will be required to reach the final operational orbit.

At this stage of the project, a Rideshare launch is considered. The deployment of a cluster of spacecraft provides a substantial level of service of **GEOScan**, without having to wait for the production, testing, and completion of the full constellation. Ideally, **GEOScan** achieves enough performance level with the first cluster of launched spacecraft to later increase that level of performance with each cluster of spacecraft launched.

3.8 Ground Segment

The **GEOScan** Ground Segment encompasses ground stations for data and telemetry download and command upload, and the Mission Control Center, which is responsible for the satellite operations, data processing, and the customer interface.

3.8.1 Ground Stations

More ground station service providers are now available to overcome the drawbacks of building a dedicated antenna for each commercial space mission. Renting an external ground station service allows saving the time and the big cost investment necessary to build a ground antenna and the complexity of maintaining it.

For this reason, NAVIR is renting the services of a global antenna network for the communication of **GEOScan**. There are different options available that meet the requirements of **GEOScan**, e.g. Kongsberg Satellite Services (KSAT) and Amazon Web Services (AWS). Specific requirements are posed on the ground stations to obtain a robust and reliable communication link, as shown in Table 3-7.

Characteristic	Value
GEOScan contacts per day per satellite	12
Time per contact per satellite for uplink	2 minutes
Time per contact per satellite for downlink	3 minutes
Frequency support needed from the ground station	S-band uplink S-band downlink X-band downlink
Min. ground station antenna size	3.7 meter
Min. elevation angle ground station	20°

Table 3-7 Ground station main characteristics.

The simulations performed in STK, considering the parameters indicated above, show that four ground station antennas, located in Hawaii (US), Cordoba (Argentina), Hartebeesthoek (South Africa) and Mingenew (Australia), guarantee constant visibility and connectivity with the fleet of **GEOScan** spacecraft, as seen in Figure 3-12. Moreover, considering that they are not close to the equator, the attenuation generated by rain is small on the transmitted and received signals. Since the elevation angle is not low, there are not considerable disturbances from the atmosphere and ionosphere and interferences with ground structures.

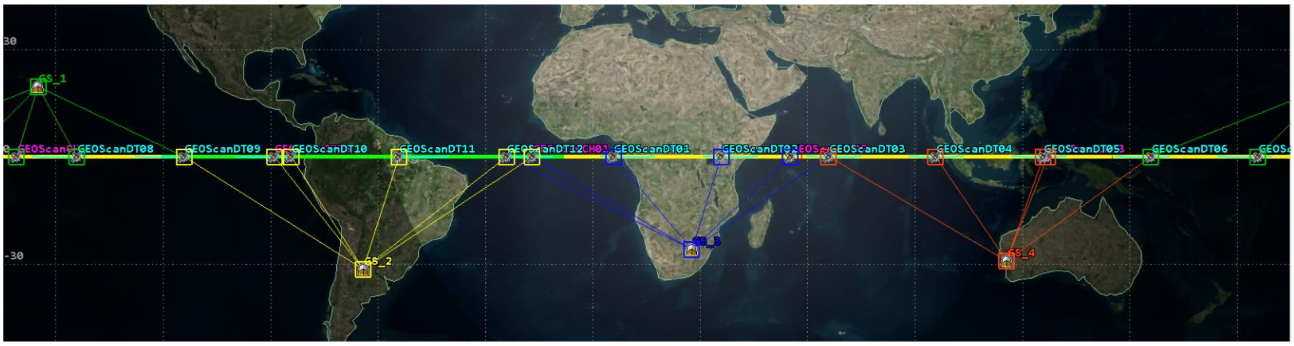


Figure 3-12 **GEOScan** visibility considering four ground stations with 20 degrees elevation angle.

3.8.2 Mission Operations

The mission operations will be conducted from the Mission Control Center (MCC), based in Europe. The MCC will be staffed 24/7 and carry out the essential functions for the spacecraft operations and data processing.

The baseline operations scenario for the **GEOScan** DETECT & TRACK constellation foresees an operation cycle of about 75 minutes, split between the following activities:

1. Perform a scan covering a vertical section of the full GEO region;
2. Perform a scan of active spacecraft residing at a 0-degree inclination ensuring frequent revisit;
3. Perform observations of newly detected or conjunction critical RSOs according to an observation schedule;

4. Download observation data and telemetry to the ground and receive updated observation and spacecraft operations schedules.

In case of an inspection request, the MCC will analyse the request to identify the optimal **GEOScan** spacecraft to carry out the inspection. Then, the MCC will update the respective spacecraft operations schedule to include the necessary manoeuvres and observations. During an inspection, the DETECT & TRACK service will have a remaining availability of at least 75% for a duration not to exceed five days.

The baseline operations of the **GEOScan** CHARACTERIZE spacecraft are less complex and encompass an observation, communications and operations schedule based on the specific active spacecraft to be characterised within each satellite's daily pass with an average of two spacecraft characterised per day.

The responsibility of the MCC with regards to spacecraft operations is the continuous optimisation of the observation schedule for all spacecraft and monitoring the spacecraft health, and correct execution of planned operations.

A team of 40 people is baselined to carry out the spacecraft operations, data operations, and online customer support split into teams covering a rotating shift schedule.

3.8.3 Data Processing

The data processing function of the ground segment is responsible for deriving the information needed to deliver customer services from the acquired observations. All data received from the space segment will be processed and archived in the data centre. According to the service the data belongs to, the acquired optical signal information will be translated into time-tagged object locations and velocities, spacecraft characteristics, or simply reconstructed into high-resolution images.

For the **GEOScan** DETECT & TRACK service, the object information is further processed by first running a correlation engine on the data to identify the observed object within the company object database repository, which includes all known characteristics of the objects to optimise correlation. The orbital elements of the identified object will then be reprocessed, taking the new observation into account. A conjunction detection software will be run regularly based on our covariance estimations and orbit propagators with precise perturbation models to provide collision avoidance warnings. The service further entails providing and analysing recommended collision avoidance manoeuvres and coordination with other spacecraft operators if the conjunction involves two active objects.

3.8.4 Service Provision

NAVIR is concerned about the safety of spacecraft operators and how customers receive and experience the services. This is the reason why on top of the three services presented before, NAVIR develops and brings to its customers the Window to the GEO Region with **GEOScan** Cupola: a new, very innovative, and user-friendly platform in which the customers do not only have the most accurate data available but can also access this via a secure, user-friendly, self-service platform.

This platform allows customers to select the type of notifications they want to receive and adapt their profile and the visualisation windows to their needs. It enables customers to navigate through the different data gathered for the three available services they subscribe to and have personalised support and assessment if they have specific requests. A first draft of the design of the user interface is available in the images below.

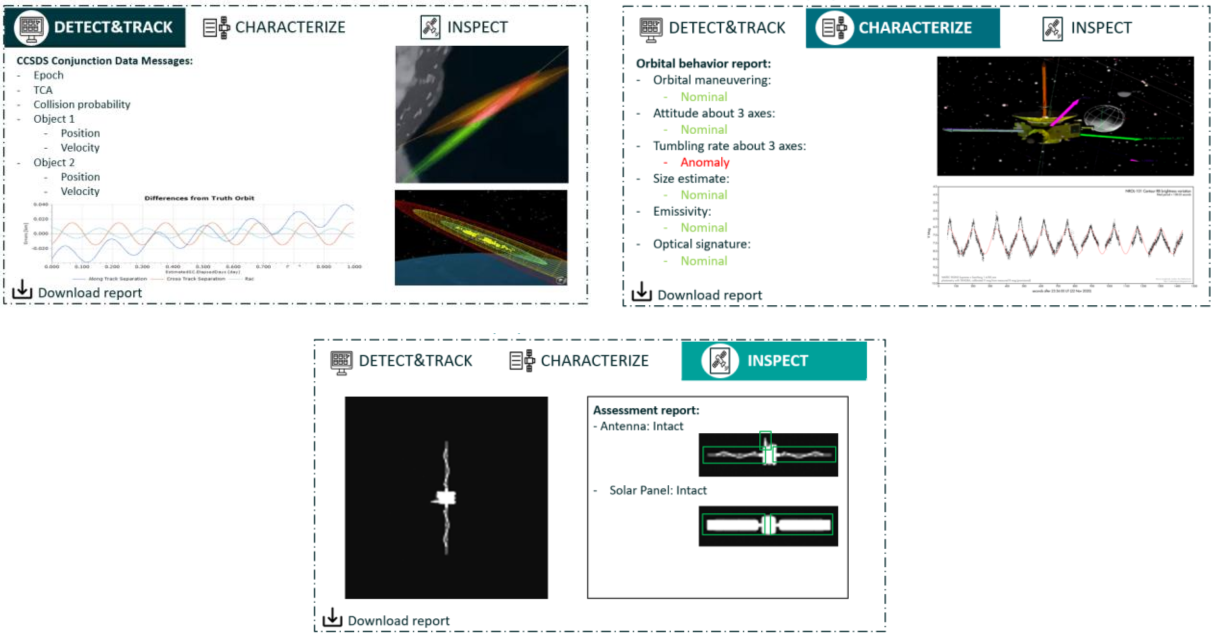


Figure 3-13 GEOCupola user interface (impression)

3.9 Compliance Statement

The presented mission is fully compliant with the set of Key Performance Parameters.

KPP Title	KPP Description	Compliance
Size	Detect RSOs of size > 10 cm anywhere in the GEO region.	☑
Periodicity	Observe >90% of all registered RSOs in the company repository every 48 hours.	☑
Change detection	Observe all active spacecraft in GEO every 24 hours.	☑
Characterisation	Obtain size and shape information on all active spacecraft in GEO with an accuracy of +/-2 m.	☑
Resolution	Upon request, obtain optical images of spacecraft in GEO with a spatial object resolution of 20 cm.	☑

Table 3-8 KPP compliance matrix.

4 IMPLEMENTATION PLAN

NAVIR plans to provide services incrementally, building upon the implementation plan. This approach matches the overall strategy to prove capabilities and attract the right level of investment at the right time. The incremental approach allows NAVIR and our **GEOScan** system to:

- Reduce the program and technical risks;
- Generate revenue from services before full system readiness;
- Build awareness of our system, capabilities;
- Develop our brand;
- Supply capabilities;
- Incrementally gain market share;

The following figure shows the implementation logic alongside the services and target market share discussed in Section 5.1.

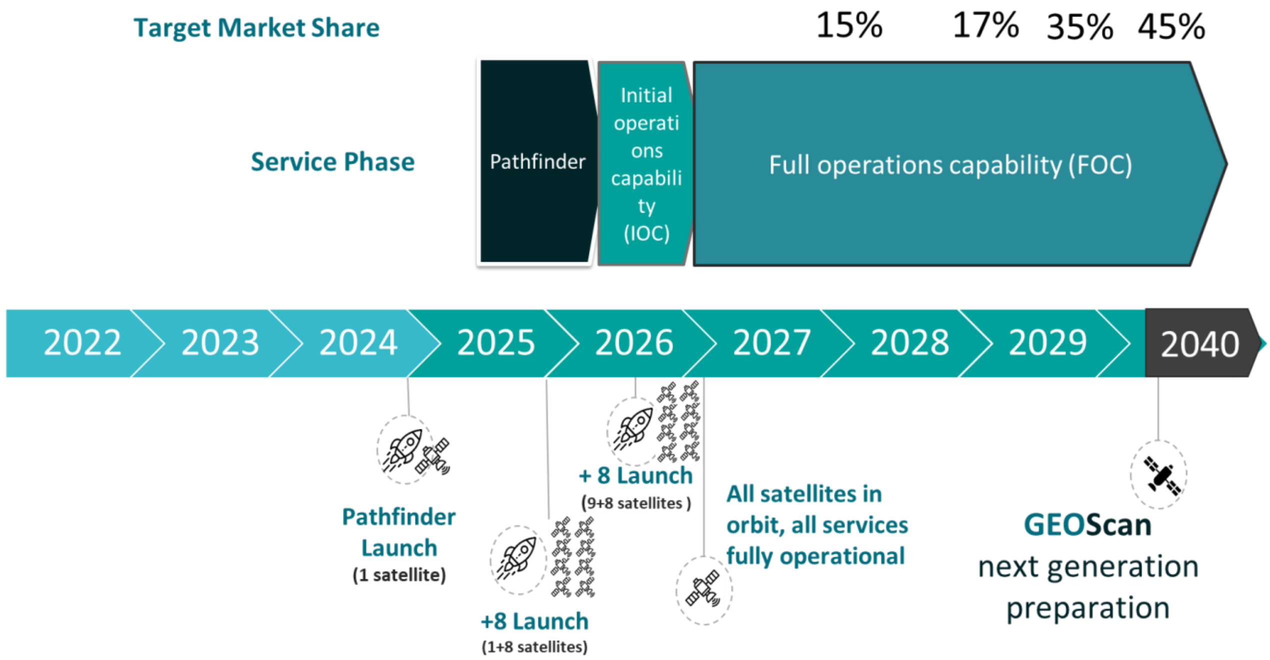


Figure 4-1 GEOScan implementation plan and target market share.

4.1 Risk Assessment and Mitigation

NAVIR follows a structured risk management process aligned with the European Cooperation for Space Standardization ECSS-M-ST-80C. A detailed technical risk register captures the risks of the **GEOScan** mission. These risks have an impact on cost, schedule and technical feasibility. All documented risks include at least one mitigation action to reduce the severity and/or likelihood to acceptable levels. Risk assessment, treatment planning, including mitigation, is applied continuously within the business.

A complete risk analysis is available, with the most critical risks identified below.

Title	Description	Mitigation
Insufficient Cash flow - Upfront Investment Needed	NAVIR requires significant funding within the first years until sufficient revenue is generated to cover costs. If this risk occurs, there is the possibility that the business is unable to pay bills or to continue to function.	• Mitigate the risk by obtaining a mix of funding sources with sufficient cash flow to cover the short term business needs and to reduce dependency on a single group of investors • Mitigate and share the risk using a Flatsat and Pathfinder and with the support of ESA/European institutions. This approach will assist in giving credibility to the business and allows us to engage and gain investors' confidence. • Reduce the size of the risk by incrementally generating early revenue.
Compliance with International Telecommuni-cations Union (ITU) regulations	If NAVIR is unable to obtain a licence in time, there is the possibility we will be unable to launch, which will incur costs and delays to our activities.	• Initiate the ITU assessment and licence application as soon as possible, with the intent to commence at Critical Design Review (CDR). We will also obtain support from experts with experience (such as ESA) and political power (such as public institutions such as European Commission) to support our application.
Services not generating income as expected	If the GEOScan services fail to generate the desired revenue, there is the possibility that NAVIR will be unable to pay the bills or continue to function.	• Multiple services allowing for dynamic adaptation to the market • Early customer involvement in the development process. Regular outreach and engagement to gain market awareness.
Payload	Payload has a lower than 6 Technology Readiness Level (TRL) at PDR or insufficient performance	• Engage potential manufacturers early enough in the project. • Select strategic partner with experience • Start with high enough TRL • ITAR free components • Perform extensive simulations • Early start of verification activities • Intermediate verification steps to measure performance incrementally • Cooperation with ESA and other industry experts during development and qualification • De-risk with Pathfinder
Achieve scanning pattern / ADCS performance	The pointing accuracy, system stability and dynamic performance does not meet observation requirements when combined with the optical payload performance.	• Perform extensive modelling • Perform early start of verification activities • Perform intermediate verification steps to measure performance incrementally • De-risk with Pathfinder
Software Development	The software does not perform to spec or is not ready on time with the required performance.	• Use agile methodologies • Start development early • Continuous integration of ground segment and space segment software • Use of COTS software components whenever possible • Perform a System Capability Demonstration 1 (SCD1 - on-ground software demonstration) • Perform on ground / on-board demonstration with Flatsat (SCD2)

Table 4-1 Main risks identified.

5 BUSINESS SOLUTION

5.1 Target Market and Competition

There are 560 active satellites in orbit. We assume 482 satellites are owned by operators in countries where we can develop the business. The number of operational satellites is expected to grow to around 600 by 2030 with a combined value of €78 bn. The commercial sector also generates an estimated €36 bn in revenue from its GEO services. NAVIR, with its **GEOScan** system, initially targets GEO satellite operators.

There are opportunities to partner with current providers of SSA services, such as the European Union - Space Surveillance and Tracking (EU-SST), Combined Space Operations Centre (CSpOC), and the Space Data Association (SDA). NAVIR's main direct competitor is ExoAnalytic Solutions who declare the ability to detect objects of 40 cm compared to **GEOScan**'s target of 10 cm.

We assume a reasonable market penetration of 150 satellites for the first four years and the subsequent six years, 470 satellites of the GEO market (560 satellites in orbit). The business model is based on offering a very competitive price for the Conjunction Data Messages (CDM) (€157K) compared to the internal cost of the operators for similar operations.

The majority of current users rely on data provided by (CSpOC), which is United States (US) based. The United States government (CSpOC) recently reported the goal of transferring civilian SSA to the commercial domain. Still, many other non-US organisations and countries rely on its data. There are similar initiatives within Russia and China, which are not accessible outside of these regions.

NAVIR sees CSpOC as a potential partner. Opportunities include data fusion of the CSpOC data repository with the database of NAVIR **GEOScan.** As **GEOScan** has unique exquisite data, CSpOC will benefit from being a customer of our services.

Other space situational awareness users include the Space Data Association (SDA). They provide current commercial operators with a platform to exchange ephemeris data and perform their own conjunction analysis. The SDA relies on CSpOC data and the transparency of operators to share their information in case of a possible alert. Many synergies will benefit both NAVIR and SDA to partner and become customers due to our unique services.

ExoAnalytics provides commercial services using Earth-based optical sensors. We consider this company as NAVIR **GEOScan** main competitor.

Figure 5-1 Potential partners for NAVIR and **GEOScan.**

The European Union Space Surveillance and Tracking (EU-SST) aims to provide European based military and institutional services to have autonomy from the US CSpOC. Their approach is to have distributed services over European countries. EU-SST objective is to build an Earth-based observation system to obtain a catalogue of objects of 35 cm and larger observed within the GEO ring by 2028. As we base NAVIRs head office in Europe, partnering with ESA and institutions, we are positioned to offer complementary services to assist EU-SST capabilities and European autonomy.

The **GEOScan** solution will provide complementary and unique commercial services that significantly improve current capabilities allowing NAVIR to be an essential and valued partner in this market.

5.2 Business Model, Marketing and Sales

5.2.1 Business Model, Marketing and Pricing

NAVIR has engaged potential customers since day one and foresees concurrent client engagement in customer and partnership roles.

Our products have compelling, unique selling points, including:

DETECT & TRACK

- Exquisite accurate position of objects greater than 10cm in/near GEO orbit;
- Tighter covariance compared to existing capabilities;
- More accurate probability of collision alerts from a single trusted source.

CHARACTERISE

- 2 m (1 m pixel size) resolution on all objects facilitating improved ability to distinguish one object from another, ascertain tumbling rate, capture a unique optical signature, capture object behaviour and detect changes.

INSPECT

- 20 cm resolution, 360-degree images of selected objects to determine configuration, damage and support malfunction detection, and service recovery.

NAVIR offers both subscriptions monthly and on-demand for the **DETECT & TRACK** and **CHARACTERISE** products. **INSPECT** is being provided on an on-demand basis. On-demand sales are priced to incentivise the take-up of subscriptions, engage the customers and quickly gain market share and revenues.

Pricing is flexible for large users and institutions due to the potential revenues. Discounts are available for multiple objects with published price breaks of 5% for five satellites and 10% for ten satellites.

DETECT & TRACK from €150 k per year based on a monthly subscription per object, on-demand is €10 k for 1-week access to service per object. Additional options are available.

CHARACTERISE from €180 k per year subscription per object for monthly reports, €100 k for the latest monthly report on an object. Subscription for the monthly global report is priced at €6 M per year. Options include on-update changes and alerts via our portal.

INSPECT prices are set initially at €2 M per inspection and can be observing the target object within 48 hours and remain for 48 hours. Options can be taken to continue inspections for more extended periods.

To showcase the high fidelity of **GEOScan** data, NAVIR gives users access to the NAVIR web portal that enables them to use and check the data quality. Key customers are invited to participate in the user of a beta version of our services. This approach helps to engage the clients and improve the delivered service quality before our constellation becomes fully operational. NAVIR plans to organise workshops and industry days, and to participate in industry symposiums and conferences.

The **GEOScan** solution provides complementary and unique commercial services that significantly improve current capabilities allowing NAVIR to be an essential and valued partner in this market.

5.2.2 GEOScan Value Proposition

GEOScan captures the estimated 30,000 non-catalogued objects of 10 cm & greater in GEO, performs collision detection, characterises distinguishing features and can perform high-resolution inspections for our clients.

These services offer technical improvements, but our end-to-end collision detection solution can significantly reduce operators' workload and help maximise the useful lifetime of the satellites.

Using **GEOScan** services can reduce the estimated annual 450 alerts to 90 per satellite, saving as much as €90 K per annum in unnecessary workload for operators. The resulting reduction of collision avoidance manoeuvres from the current 2 per year per satellite to 1 every three years is estimated to save up to €580 K per annum in lost revenue and related fuel, helping to maximise the satellite's lifetime.

The **GEOScan** Characterise and Inspect services enable operators to gather additional information regarding their operational spacecraft and gain essential parameters if there is an unexpected change. This information will augment the telemetry and assist operators in identifying the root cause of their anomaly and recovering their spacecraft.

Figure 5-2 Benefits for users of Detect & Track.

Figure 5-3 Example benefits from **GEOScan** Inspect service.

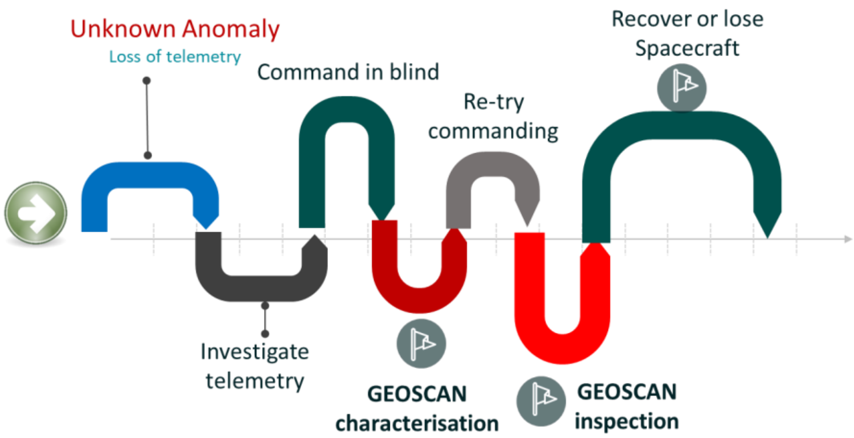


Figure 5-4 Example scenario where **GEOScan** services assist operators in recovering from a satellite anomaly.

When a satellite experiences significant anomalies, even telemetry can be unavailable. In such situations, the operator may try for an extended period of between 30 and 60 days before finally declaring the satellite lost. During this time, the organisation will lose service revenue and haemorrhage money on resources that may cost them more than €13 M.

The activities can involve teams of specialists and consultants to understand the problem and recover the satellite and its services, as shown in the figure on the right. Suppose this team uses the **GEOScan** Characterize and Inspect Services. In that case, they can reduce the time necessary to investigate and understand the situation, minimise revenue loss, workload, and, more importantly, potentially recover their critical satellite.

5.2.3 GEOScan Market Adaptability

NAVIR provides flexibility to adapt to market needs. The satellites can quickly adapt to the market needs and reconfigure accordingly.

With **GEOScan**, NAVIR has designed a constellation based on two significant elements:
- Modularity and
- Reconfigurability.

This ability for NAVIR to dynamically adapt its services to the market will enable the business to grow efficiently.

5.2.4 NAVIR Finance

5.2.4.1 GEOScan Revenues

NAVIR will slowly increase the market share and revenues, but once the full constellation and services are online, they will grow rapidly.

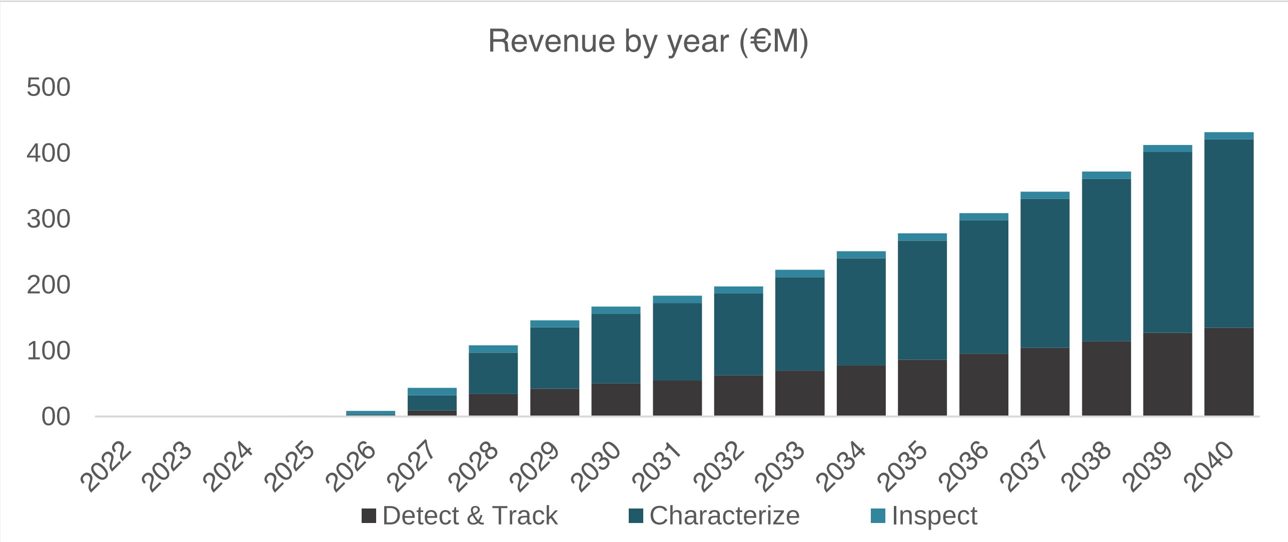


Figure 5-5 GEOScan revenue per year.

The full information by year and service is contained within the finance model.
Some of the key figures are captured in the following table:

Dates	Service phase	Combined Revenue	Cumulative Revenue	Target Market Share	Product	Revenue
2025	**Pathfinder**	1	1	< 1%	Characterise	1
2030	**Full Operations capability**	166	475	25%	Detect & Track	50
					Characterise	105
					Inspect	11
2035	**Full Operations capability**	279	1,607	45%	Detect & Track	87
					Characterise	181
					Inspect	11

Table 5-1 *Revenue and market share summary (all figures in €M).*

Overall, NAVIR achieves a positive cash flow (without financing) by 2027, an overall net profit margin of 83% by 2035 and a compound annual growth rate of 65%.

The incremental revenue and separation approach into three complementary but separate services enables NAVIR **GEOScan** to adapt to the market, and the planned revenue demonstrates a solid and profitable business.

5.2.5 NAVIR Funding Structure and Valuation

Launching activities in 2022, NAVIR plans to demonstrate the capabilities and proof of concept with the Pathfinder. The Pathfinder will reach orbit in 2025 with first service capability after mid-2025. The de-risk & marketing strategy also includes software demonstrators and a flatsat to engage and retain interest from partners and investors.

NAVIR will develop 16 satellites within two years, using European companies with an industrial heritage to build constellations within the required time frame.

GEOScan spacecraft need a direct injection into the GEO orbit. The preferred option is to have European providers launch the **GEOScan** constellation. This procurement approach is conditional upon obtaining a competitive price and institutional support.

The funding structure needed for the **GEOScan** system starts in 2022 with an initial amount of €9.7 M and finish in 2026 with €132.5 M. In the early stage of the mission, the 11 founders of NAVIR will invest an amount of €110 K and receive from family and friends €550 K. In this early stage, NAVIR plans to acquire additional yearly payments from ESA and public sources until 2024.

From 2023, the target is to have three different rounds from two venture capital investors, with a total amount of €141 M and €155 M from each investor.

Once **GEOScan** has started its services and begins receiving revenues, NAVIR targets to get loans from four different banks. In 2025 the loan is €31.5 M having an interest of 5%, and €26.5 M in 2026, at 4% interest.

These funding activities are summarised in the table below. Further explanation of the funding from institutions is presented in the next section.

	2022 €9.66M	2023 €33.77M	2024 €50.16M	2025 €196.50M	2026 €132.50M
	€0.11M				
	€0.55M				
esa	€4.00M	€16.77M	€11.00M		
Public	€5.00M	€17.00M	€14.16M		
			VC 1: €12.00M VC 2: €13.00M	VC 1: €80.00M VC 2: €85.00M	VC 1: €49.00M VC 2: €57.00M
BANK				BL 1: €16.50M BL 2: €15.00M 5% interest	BL 3: €14.00M BL 4: €12.50M 4% interest

BL: Bank Loan; VC: Venture Capital

Table 5-2 Overview of funding sources for NAVIR and GEO**Scan.**

In terms of valuation, in the first investors round, NAVIR will have a value of €215 M. One year later, the valuation will increase to €485 M, and in 2025 the valuation will be €1.6 bn. By 2035, NAVIR will be a unique company because of our unique and exquisite services and customer relationship, the brand NAVIR and **GEOScan**, our highly experienced team, our vision and assets. The value at that final stage of the mission lifetime is estimated to be €8.3 bn. This value will generate a multiple of 10 return on investment. Each investor will hold 16% and 26% of the company shares, respectively. Based on continued revenue, market with our vision of expansion, it is anticipated that NAVIR will be valued at over €12 bn by 2040.

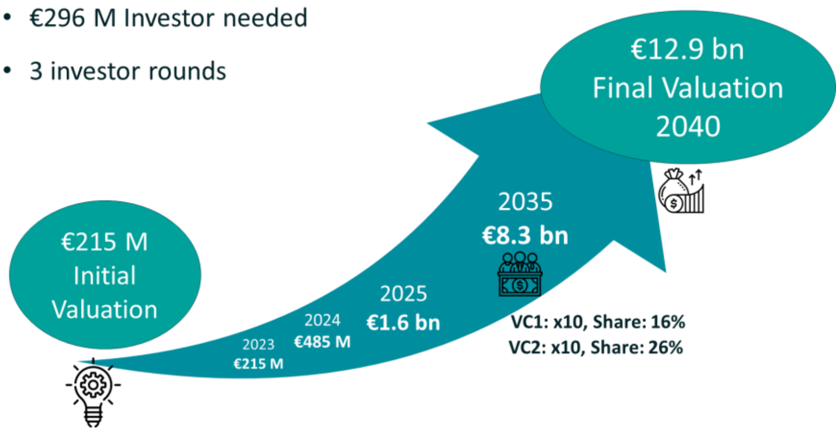


Table 5-3 Valuation of NAVIR, investor funding and shareholding.

5.2.6 GEOScan Public, Private Partnership

Public funding is needed to ensure the maturity of the design and consolidate the development of the Pathfinder. The need for the European Space Agency technical support and the related technical standards that control the quality and reliability of the end products are essential for NAVIR to de-risk the first satellite of the fleet. We propose to have a contract in co-funding scheme between NAVIR and ESA with the European public institutions to cover the development of the payload, space and ground segment, and the cost of the launcher.

5.2.7 NAVIR Vision for Scaling the Business

GEOScan is the first step in NAVIR's plans. NAVIR will become the point of reference for on-orbit satellite services related to inspection and characterisation and will be the owner of the most exquisite data repository on space debris in geostationary orbit.

There are related nascent missions such as Active Debris Removal (ADR) and On-Orbit Servicing (OOS) that do not yet have a mature market but are an attractive area to scale. **GEOScan** is in a position to offer complementary services such as mission surveys, activity monitoring and object inspections.

Five years after operating the **GEOScan** constellation, a dedicated project team will prepare the **GEOScan NG** (Next Generation) with an augmented capacity for detection and tracking with high-resolution optical payloads. This optical payload is planned to support video streaming, enabling visual assistance to support in-orbit refuelling, space debris removal and satellite de-orbit. In addition, it will include flexible payload support capability enabling In-Orbit demonstration (IOD) services for software and hardware in-orbit validations to de-risk future telecom and Earth observation missions.

In parallel to the renewal of the **GEOScan** fleet, a new constellation called "**LEOScan**" will be designed and a Pathfinder built to expand the business in Low Earth Orbit (LEO).

NAVIR has built a credible business expansion plan on the current needs of stakeholders and the existing trend in the space market, as shown in the roadmap below.

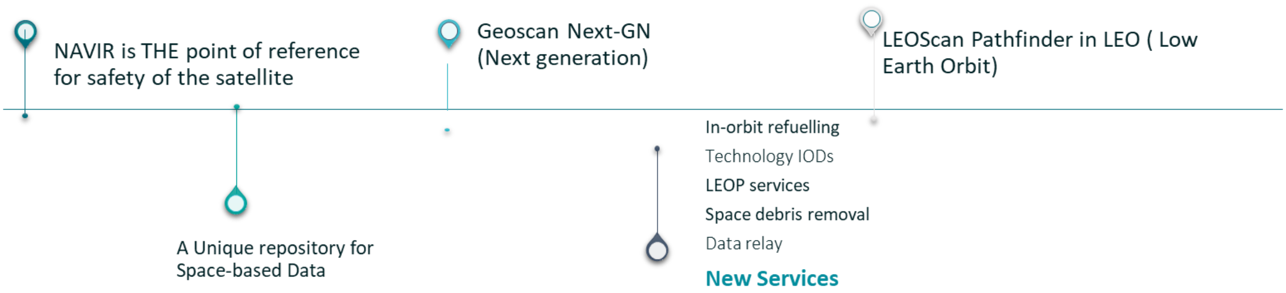


Figure 5-6 NAVIR vision for scaling the business.

5.3 Business Summary

By developing and launching the first satellite of the constellation through the pathfinder approach, NAVIR consolidates its constellation design and de-risks the related development thanks to ESA's and public institutions' technical and financial support. The Pathfinder and funding approach reduces the burden on the business whilst providing credibility, stability, and a European base that will be attractive to potential investors.

To obtain revenues, NAVIR will implement an early deployment of service with a gradual ramp-up until the full constellation is in orbit. At this point, revenues and market share will climb rapidly, with positive cash flow starting in 2027.

NAVIR will quickly gain a prominent place in the Space Situational Awareness market as it is a novel mission concept with unique, exquisite services.

When combined with multiple, complementary services, the flexible design of the constellation and orbit regime will help us adapt to market changes and needs. As shown in the previous sections, our model and approach are credible and realistic, leading to strong returns and high market share.

6 CONCLUSION

The innovative **GEOScan** system brings new and better eyes to the GEO region, providing information that is not available at the moment but desperately needed for safe and sustained space operations. **GEOScan** provides the products that customers cannot find in the current market, for example:

- Accurate location information on ALL objects in the GEO region that can threaten active space systems and not only the largest objects;
- Tighter covariance values on objects in the GEO region;
- Characterisation information up to 2 m in resolution on both active systems and large objects in GEO;
- On-demand, swift inspection of satellites in case of anomalies.

Independent research shows a large growth in the business value of space assets in the GEO region but also in the expected number of space objects in this region. The established early identification of the current SSA gaps ensures that NAVIR offers a unique solution on the market for a competitive price.

The **GEOScan** constellation covers the gap that the current SSA sensors have and improves safety and sustainability in the essential GEO region. The lightweight space segment is built from mainly COTS components, and the use of existing facilities and ground stations provides both flexibility and a low-cost structure to NAVIR.

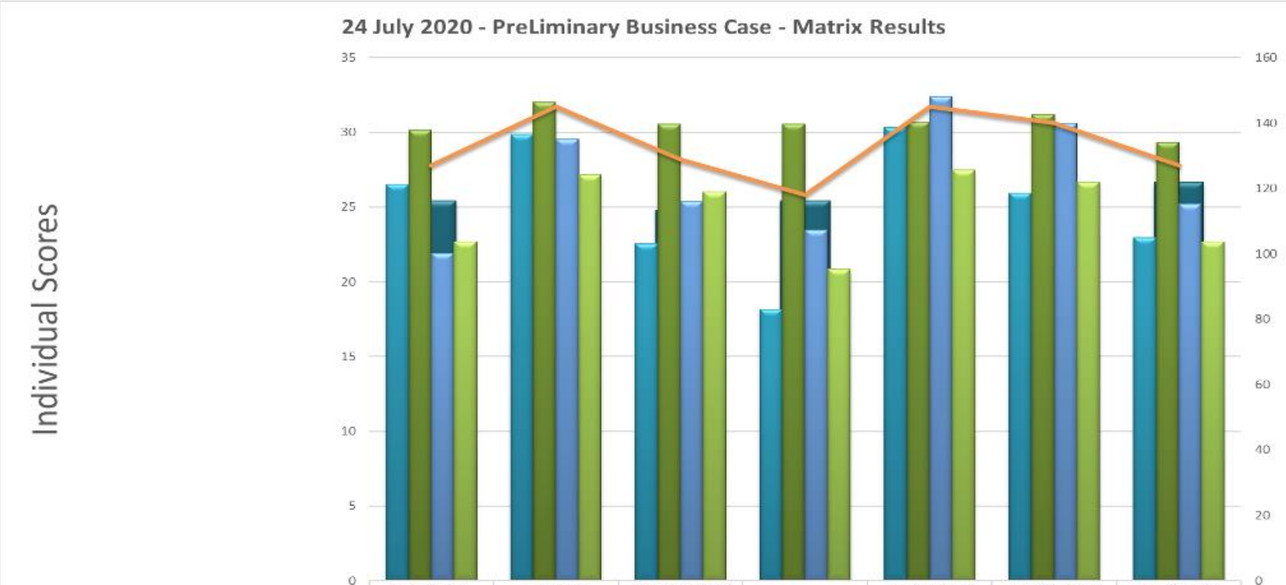
Not only will GEOScan redefine the definition of accurate information in GEO. It can do so in a commercially viable way while supporting the development of European industry in the process.

GEOScan: See better, see more.

ANNEX 1 – PROCESS OF THE CCP PROJECT

The aforementioned solution for SDA / SSA in the GEO ring was conceived through a rigorous academic activity called the Central Case Project (CCP) that was part of the Masters of Engineering Programme SpaceTech offered by the Technical University of Graz. At the onset of the CCP, the programme participants were briefed about the alarming issue of an exponential increase in RSOs that can lead to a cascading collision-chain called the Kessler Syndrome. In the first phase of the CCP, the team conducted a thorough investigation of the SSA / SDA market by conducting a series of interviews with major stakeholders in this domain. Along with the interviews, the members of the Business Engineering team produced a thorough **Market Survey & Analysis** (MSA) that highlighted the dire need for a sustainable and effective space monitoring solution. The MSA found that the problem of uncertainty in RSO ephemerides is significantly more pronounced in the GEO orbit due to its altitude as opposed to the LEO orbit.

After successfully conducting the MSA, the SpaceTech team members went through a round of pitching innovative ideas in all orbital regimes. The innovative ideas were explored from a system engineering and business engineering perspective using a weighted decision matrix. These ideas spanned over a wide range of ideas; from active debris removal to piggyback in-situ SSA observatories. These ideas were weighed on the criteria of addressing space sustainability, technical feasibility, sufficient customer base. The results are shown below:



	1. Emilio (IO NILOS)	2. Melanie (LEOShield)	3. Georgos (MEO) RSO	4. Sergio (LEO)	5. Julien (GEO) 5cm + RFI	6. Emilio (GEO OBSERVATORY)	7. Julien (LEO Laster)
4 Addresses Space Sustainability	25.42	25.916	24.8	25.42	23.963	25.203	26.66
1 Technically Feasible	26.527	29.889	22.55	18.163	30.34	25.953	22.96
2 Interesting CCP Topic	30.12	32	30.56	30.56	30.68	31.2	29.32
3 Sufficient Customers/revenue Available	21.915	29.565	25.38	23.445	32.4	30.6	25.2
5 Acceptable Time to Reach Operational Readiness	22.68	27.16	26	20.84	27.48	26.68	22.68
Totals	127	145	129	118	145	140	127

Figure 0-1 Weighted decision matrix for the seven initial Business cases.

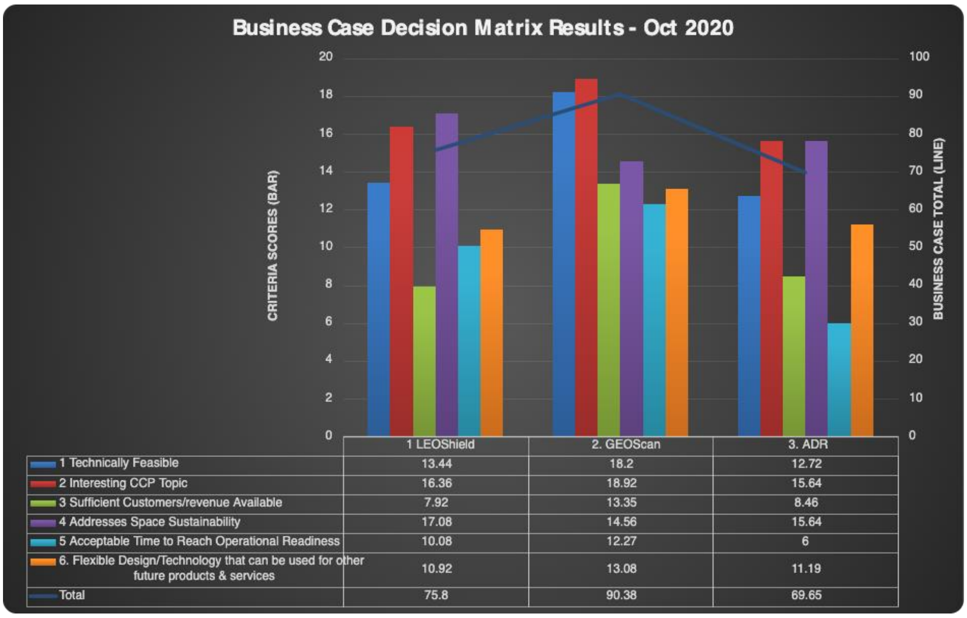
The seven innovative solutions went through a round of Elevator Pitches in the presence of both the programme coaches and the stakeholders. After thorough deliberation and scoring, three out of seven pitches were selected based on their viability from a system and business engineering POV. These three ideas were:

1. LEOSHIELD – improving SDA in LEO using a constellation of satellites in LEO;

2. **GEOScan** - improving SDA in GEO using a constellation of satellites in sub-GEO;

3. ADR&S – active debris removal and satellite servicing for existing satellites.

The SpaceTech team then investigated the engineering and business aspects of the three chosen cases in sufficient detail to further pick the most plausible solution. Using an updated version of the decision matrix, the team, the coaches, and the available stakeholders went through detailed deliberation and scoring, thus finally choosing the **GEOScan** as the most technically and financially viable solution. The decision matrix for the final selection is shown below:



	1 LEOShield	2. GEOScan	3. ADR
1 Technically Feasible	13.44	18.2	12.72
2 Interesting CCP Topic	16.36	18.92	15.64
3 Sufficient Customers/revenue Available	7.92	13.35	8.46
4 Addresses Space Sustainability	17.08	14.56	15.64
5 Acceptable Time to Reach Operational Readiness	10.08	12.27	6
6. Flexible Design/Technology that can be used for other future products & services	10.92	13.08	11.19
Total	75.8	90.38	69.65

Figure 0-2 Weighted decision matrix for the three remaining Business cases.

It is pertinent to mention that this outcome was achieved by following Agile methodology incorporating weekly Design and Analysis Cycles (DACs) while Monday.com was used as the project management tool. The participants of the CCP were divided into three teams: Project Management, System Engineering, and Business Engineering team. Each team was led by a Product Owner (PO) and a Scrum Master (SM). The participants changed roles after every increment, which was set between 11-12 weeks. Innoslate was used as the Model-Based Systems Engineering tool for the entire project. Each artefact went through a rigorous review cycle, first from the team members and then through the coaches. The following infographic shows the processes, tools, increments, and important decisions:

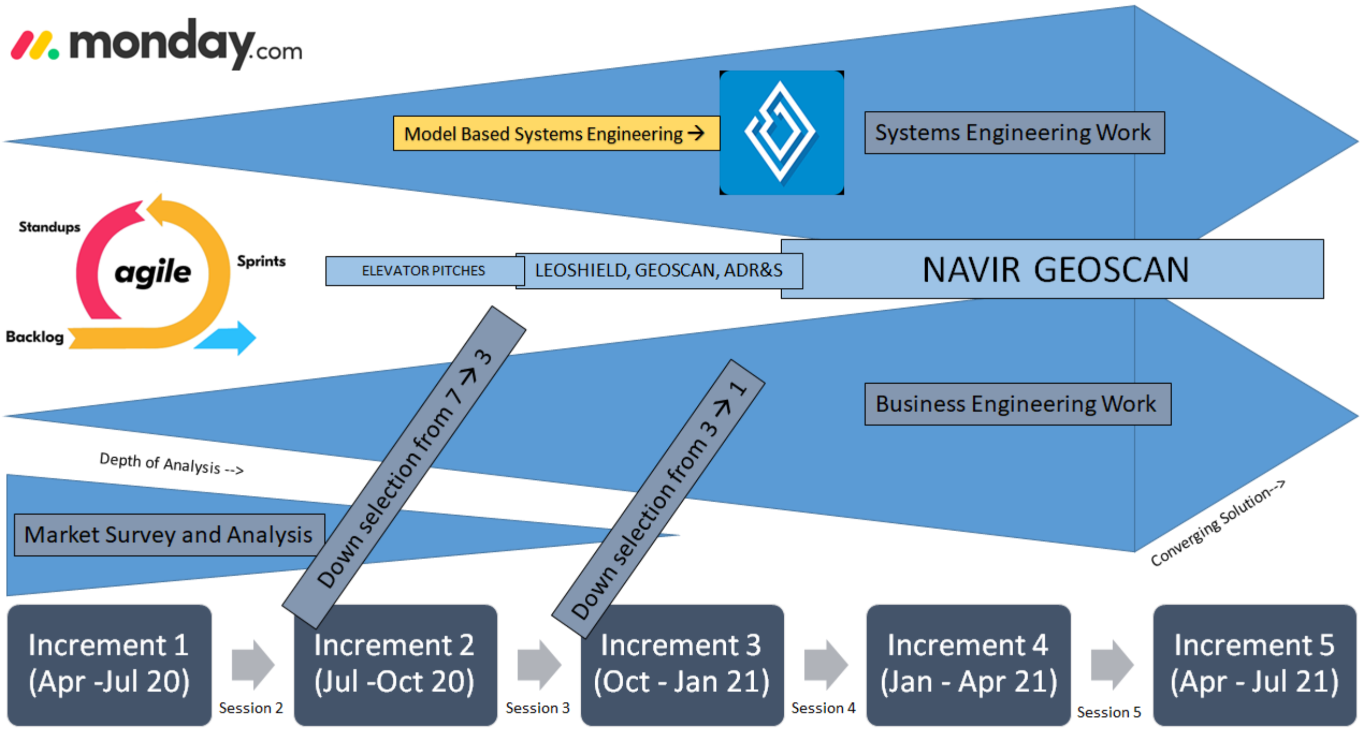


Figure 0-3 SpaceTech Central Case Project process summary.

ANNEX 2 – ACRONYMS USED

CCP	Central Case Project
CCSDS	Consultative Committee for Space Data Systems
CDM	Conjunction Data Message
ConOps	Concept of Operations
COTS	Commercial-of-the-Shelf
CSpOC	Combined Space Operations Centre
ESA	European Space Agency
EU-SST	European Union Space Surveillance and Tracking
GEO	Geostationary Orbit
IRR	Internal Rate of Return
krad	kilorad – a unit of radiation
LEO	Low Earth Orbit
MCC	Mission Control Centre
MOC	Mission Operations Centre
MSA	Market Survey Analysis
PPP	Private Public ParnershipPartnership
RSO	Resident Space Object
s/c	spacecraft
SCD	Systems Capabilities Demonstration
SDA	Space Data Association
SDA	Space Domain Awareness
SSA	Space Situational Awareness
STK	Systems Tool Kit
TRL	Technical Readiness Level
VC	Venture Capital

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