Conceptual Design of an Earth Observation Satellite for the Colombian surface SatCo1

Presented by
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Presented
by
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In partial fulfillment for the requirements of the bachelor degree of

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Acceptance Notes

Jury's president signature

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Juror's signature

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Dedicación

Para mi madre y familia quienes me han apoyado enormemente durante estos seis años llenos de retos, aprendizaje, felicidad y deseos, igualmente que a mis profesores quienes me inspiraron a seguir mis sueños y hacerlos realidad.

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Abbreviations and Definition of terms

AOCS: Attitude and Orbit Control System.
CCE: Colombian Space Comission *(Comisión Colombiana del Espacio)*
CN: Constraint Consecutive.
COEs: Classic Orbital Elements.
CONAE: National Commission of Aerospace *(Comision Nacional de Actividades Aeroespaciales)*
CUSTOMER: Is the body in charge on the financing of the project and will determine/choose the user(s).
DEC: Decision- Go/no go.
DNP: National Planning department *(Departamento Nacional de planeación).*
DRI: System Drivers consecutive.
EAS: Element for the Propulsion, thermal and AOCS Subsystems.
ECS: Element for the communications, telemetry and command subsystems.
ECSS: European Cooperation for Space Standardization.
EDS: Element for the Data Handling Subsystem.
ELE: Element application.
EPS: Element for the Power Subsystem.
ERS: Element for remote sensing Subsystem.
ESA: European Space Agency.
ESS: Element for the Structure and mechanisms Subsystem.
FA: Functional Attribute.
FIRESAT: Satellite's name of EE. UU mission of an Earth Observation Satellite.
FUA: Functional Attribute.
FUR: Functional requirement.
GEO: Geostationary orbit.
ICT: Information and communication technologies.
IGAC: Geographic institute Agustín Codazzi (*Instituto Geográfico Agustín Codazzi).*
INCOSE: The International Council on Systems Engineering.
LEO: Low Earth Orbits.
LIDAR: light amplification by stimulated emission of radiation.
MEO: medium earth orbit.
MDR: The Mission design review.
MIE: Mission Elements.
MWs: Momentum wheels.
NASA: National Aeronautics and Space Administration.
ND: User/Customer needs.
NWD: No working day.

NºC: Number of consecutive.
OCDE: Organization for the economic and the social development (*Organisation de coopération et de développement économiques*).
PCO: Preliminary constraints.
PDR: Preliminary design review.
PEP: Performance parameter.
PFR: Preliminary functional requirement.
POR: Preliminary operational requirement.
PRR: Preliminary requirements review.
QFD: quality function deployment.
QFUR: Quantifiable functional requirement.
QF-T: Quantifiable Functional & technical requirement.
QTR: Quantifiable technical requirement.
RANN: Right Ascension of the Ascending Node.
RW: Reaction wheel.
SATCO1: Name of the Satellite project presented in this document
SBS: Subsystem affected.
SELPER: Latin-American Society of Specialists in Remote Perception and Geographic Systems Information *(Sociedad Latinoamericana de Especialistas en Percepción Remota y Sistemas de Información Geográfica).*
SMAD: Space Mission Analysis and Design.
SRR: Systems requirements review.
SS-O: Sun-synchronous orbit.
Stakeholder: Customer/User or group that has a concern on the project development.
TEC: Technical Characteristic.
USER: Is the body that is going to take advantage of the project (to use it), and will perform actions with it.

ABSTRACT

The Earth Observation in Colombia is a fundamental topic where research, development and studies are needed according to the Colombian Space Commission [8]. Looking forward to accomplishing different applications on health, defence, environmental and space research. However, in the country there are few studies on this topic.
This document has been developed using as reference the needs of researching on topics for the Colombian Earth Observation by means of LEO satellites hence, a conceptual process has been performed identifying similar papers of LEO Observation satellites but not focused on the Colombian Space itself.

This document has been selected in order to elaborate a conceptual design focused on the Colombian Earth Observation requirements. By means of using the European standard [16] phases (0 and A) as for the development of the mission definition, preliminary and systems requirements along with a mission modeling for a practical understanding of the Satellite in Colombia by means of the STK [33] program. The data found and results obtained from this research are intended to be a baseline for a preliminary design project or Low Earth Observation researches likewise, to understand the different factor that affect a conceptual design process.

By examining different documents and information from the Stakeholder of the spacecraft requirements and needs, this research collects the data obtained and is adapted to the mission objectives, demonstrating a conceptual process with the analysis and documentation, which is hoped to be used as reference in future works.

Keywords: Libertad 1, Colombian Artificial Satellite, SatCo1, Systems engineering requirements, STK Colombian modeling.

OBJECTIVES

General Objective

To elaborate a conceptual design for an Earth Observation Satellite, which sets a mission definition, preliminary requirements and systems requirements based on the Colombian Earth Observation's needs.

Specific Objectives

i. To establish the main Colombian needs regarding to Earth Observation and space technologies applicable for this project.

ii. To set a preliminary Mission definition based on the conceptual research using the information and results achieved throughout this project.

iii. To define the preliminary systems and requirements needed, using the conceptual phases applicable to this project.

INTRODUCTION

This is a project of a Conceptual design of an Earth Observation Satellite for the Colombian Surface; likewise, it is based on the ECSS-E-ST-10C standard [16], which, for the Conceptual phase is standardized in the Phases zero, and A.: the mission, preliminary and systems requirements review. Moreover, this document is focused on the Colombian needs stated by the Customer and user, the National Planning Department (DNP) and the Colombian Space Commission respectively.
The National Planning department (DNP) is the body in charge of the planning and programs that are performed during the presidential term (by about four years) in Colombia. Besides, as part of the programs stated in the 2014 and 2018 plans [13], they recognize as one important objective “the development of the Space Research in Colombia” that needs to be worked on. Therefore, the DNP delegates the Colombian Space Commission as the body in charge of the Space research matters.

The Colombian Commission for the Space (CCE) was created after the presidential decree, 2442 of 2006 as the representative section for the planning, organization, research and as stage for the gathering of institutional management about: Telecommunications, satellite navigation, Earth observation, astronautics, astronomy and aerospace medicine [13]. Hence, this commission is the focal point of the space matters and it works along with different entities such as the Defense Ministry, Civil Aeronautics and the DNP [13]. Being this not only a defense but also a civil purposes commission with the aim of gathering the Space research, ever since there is not a Space Agency established in Colombia yet.

This document is limited by the Phases of the Conceptual design of the standard mentioned above, likewise, a practical analysis is performed using the Orbit satellite program STK [46], this is with the objective of giving a practical analysis of the requirements gathered during the research. Therefore, being this as a possible baseline for a future preliminary design of an Earth Observation Satellite with a Sun-synchronous orbit (SS-O).

In Colombia, in one hand, the Satellite projects background is by just one, the Libertad 1 [11]. A project developed in The Sergio Arboleda University, but on the other hand, there are no more known satellite projects, leaving these topics by far deeply explored [6]. Ever since in Colombia, the space research and projects is a field where there is no a big market competition, it becomes a good place to start those projects, not only in observation but also communications, navigation and different applications, which nowadays are subcontracted to other Countries satellites and could be contracted with a national service. However, ever since there is not much information regarding space projects (mainly Observation projects) in Colombia, it becomes a problem the lack of experience, regulations and laws for the Space in the Country. Which require time to be achieved and it may delay any advance, research, projects or applications [48]. This Gap could be solved by researching more in the Universities, establishing the specific regulations in

Colombia for the space matters and to instruct more students in the academy so more professional and specialized people on the field stay and may be of help in the huge job that lays ahead for the Space research in Colombia.

This research is presented in order to contribute to the lack of studies, research, experience and information of Earth Observation, which field has not greatly been explored in the country and it represents a crucial topic for the defense, environmental and health applications. Therefore, a SS-O satellite is proposed for the Colombian Earth Observation ever since, this technology represents the most used and common one in the Earth Observation matters. It is expected to achieve the information regarding the different phases of a conceptual design and to acquire a systematical process that allows an ordered and structured understanding of the different topics of the Conceptual process of a Space Mission.

The chapters are divided into 5, the chapter 1. Is the Framework used on the document, the chapters 2, 3, 4 and 5 are the core, which represent the "mission analysis and design- mission definition review (MDR)", "preliminary requirements review (PRR)", systems requirements review (SRR) and "mission design (parameters definition, analysis of results and simulation)" respectively; every chapter is followed using the reference from the SMAD book [8]. Afterwards, there is a chapter for the Conclusions and finally the reference used on this document.

Likewise, this document uses a Quantitative methodology that is performed examining different documents and information from the Stakeholder of the spacecraft requirements and needs along with the Standards [16] and systematic processes [8]. The different results obtained from the research are represented in chapter 5.3 and the conclusions of this document in chapter 6.

PROBLEM STATEMENT

The Colombian state has previously remarked the importance and the needs for the development of the Earth Observation researches as it is set in the national public development plans of 2014-2018 and 2018-2022 registered in the national planning department (*Departamento nacional de Planeacion* "DNP")[6].

Even though, the Earth Observation is an important topic for the DNP, there is a lack of researches, information and support in regards to this topic which is a limitation when trying to refer to projects focused on the country's needs according to reference [6]. However, there are just some analysis and reviews concerning the Colombian Earth Observation by means of "Satellite technologies" which were developed by the Commission delegated by the National Government for the Space the "CCE". Because of this, in this project it is desired to contribute to the Colombian Earth Observation by means of a research project.

It is important to understand that the Earth Observation performed by means of Satellite technologies is the most common way for the Colombian Earth Observation and at the same time it is a field greatly unexplored in the country. Acknowledging that it is needed for some applications such as the research, intelligence, defense, health and environment. For instance, according to the *Instituto Agustín Codazzi* [14] and the Earth Observation Magazine [13], there is a need of having an own remote sensing system for determining the land use and population growth, which information is currently rented to other country's satellites. It is crucial to create local technologies that can be explored by local and foreign users, hence, it is needed to start and continue different projects that are focused on the Colombian needs for the Earth Observation, projects such as papers, designs, models, and investigations.

This document has gathered and complied the information and researches of the Colombian Earth Observation needs, applications, definition of the stakeholder (user/customer) along with different systematical analysis which, may contribute to the Colombian Earth Observation researches and being this a baseline for understanding the needs of investing, researching and creating strong local technologies that shall contribute to the country. This is based on the research question that is solved throughout the project, which is:

How should a remote sensing system be performed in order to be focused on the Colombian Earth Observation and Space technology's needs?

JUSTIFICATION

With the aim of the development and research of new satellite technologies in the Colombian aerospace field this document named "Satco1" is presented using the Engineering knowledge learned in *The Fundacion Universitaria los Libertadores*, the professional experience working in an aerospace company and performing a quantitative research methodology. This project contains basis of aerospace conceptual phases researches, thermodynamics, mechanical orbits and aerospace standards for systems engineering likewise, satellite, structural, aeronautical and space projects are taken as reference for the space mission definition, preliminary requirements and systems requirements.

Artificial Satellite devices for the Earth observation can contribute to the defense, observation, research, etc. Because they have the characteristics of being available and focusing the observation on certain targets according to the desired mission. One example of this development in South America is the "China-Brazil Earth Resources Satellite Program" which objective of a partnership in the space technical sector has allowed Brazil advance and access to these complete satellite technologies [9]. This can be noticed as their images are used in important fields such as controlling deforestation and burning in the Amazon, the monitoring of water resources, agriculture, urban growth, land use, education and many other applications [10].

The Colombian Space Commission (CCE) has the objective of being a support to the Colombian country to enforce the knowledge about the Earth and Space by using modern technologies [11]. Likewise, the *Fundacion Universitaria los Libertadores* applies the research as a process to develop the knowledge in different fields such as the Engineering and Basic sciences [12]. Taking into account the previous information, this research project aims to provide some basis and start-up concepts to the Colombian Earth Observation research and development.
Even though this commission exists (the CCE) and it had one project on orbit named "*Libertad 1*" working with a Colombian University, there is a need of more research and new projects and the creation of a Colombian Space Agency. As it is stated for the "Digital transformation" (From the Colombian national plan of development 2018-2022) in its subpart five [2]. Implementation of the national policy for developing the Satellite Industry "*Implementación de la política nacional para desarrollar el sector satelital"*

METHODOLOGY

A descriptive research is when describing a situation, subject, behavior, or phenomenon. It is used to answer questions of who, what, when, where, and how associated with a particular research question or problem. Descriptive studies are often described as studies that are concerned with finding out "what is" [7]. This concept of a "descriptive research" is the one that is going to be used on this research as a result of the need of describing the preliminary requirements such as the physical structures, systems, schedule and location, this all gathered in definition of the mission.

Likewise, this conceptual project of an Earth Observation Satellite for the Colombian Earth Surface is going to use a Quantitative Methodology; this methodology has been selected based on the main objective of the project that requires the conceptual research, data collection, Mission definition, preliminary requirements and system requirements review.

The conceptual project takes into account different features such as preliminary requirements review, definition and systems therefore, methods about a descriptive research have to be noticed, one of them is the documentary research method that refers to the documentation analysis as for gathering the required descriptions using a method for information collection.

CHAPTER 1 - FRAMEWORK

1.1.Systems Engineering

Systems engineering is the first concept of this framework, ever since this process shall be the baseline to start the project along with other standards and concepts (as defined afterwards in this chapter); According to reference [36], System Engineering "is an interdisciplinary collaborative approach to derive, evolve and verify a life cycle balanced system solution that satisfies stakeholder expectations".
This project is based on the Space engineering standard ECSS-E-ST-10C [16] that is going to be further discussed in point 1.3 and it represents the system engineering step to step for developing a system engineering process, which makes part of the objective of this project.

After understanding that this project is based on a Space (systems) engineering tasks, the next thing to do is to understand what kind of mission, objectives and requirements this project has to accomplish in regards to the conceptual side, see section 1.5 "Mission Types

1.2."V"-cycle

The systems engineering can be expressed by a life cycle, which, expresses the stages of the process through a cycle (the system engineering has an iterative nature). Different life cycles can take part in the project developing including adapted to the mission of the System engineer, though in this project, this life-cycle is expresses by a "V"-cycle as shown in figure 1.1 "V-model- life cycle"
Using the reference from the "A Systems Engineering Environment for Integrated Building Design" [21], where it states a common model in "V" as a graphic tool to represent the life cycle where a verification occurs horizontally and between the definition of each phase. The descent of the "V" model defines what should be made, de ascent of the "V" model stands for the components that build the system, and it verifies the relationship of the product with regard to the specification. Is important to notice that the architectural design (third segment of figure 1.1) is the stage that this document is going achieve along with the "stakeholder and system requirements stages".

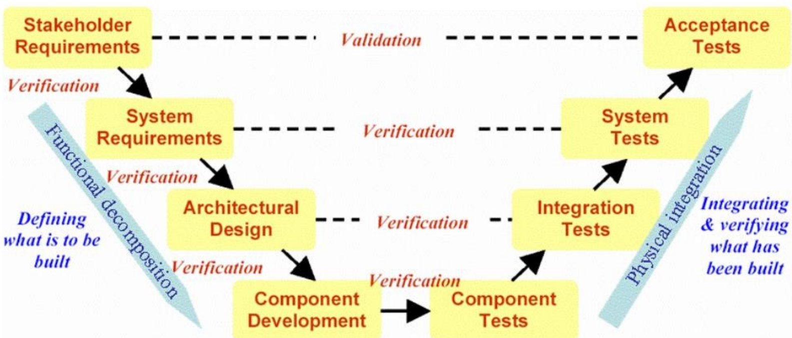

Figure 1.1. "V"-model- life cycle, taken from reference [21] (Typical SE process in form of "V"-shaped life cycle).

1.3.Space engineering standard ECSS-E-ST-10C

It is important to know about the Space engineering Standard due to the need of using a reference and steps already established for future works ever since clients, partnerships or other business need to communicate between each other in one "language" or "Standard".

As part of the life cycle in the systems engineering, there are different standards or norms and they are used in order to give systematical tasks and actions for space systems and missions; the **ECSS-E-ST-10C** standard specifies the system engineering implementation requirements for space systems and space products development [16]. This standard gives the tasks trough "phases" and those phases are the parts for developing a system engineering requirements and development baseline. These phases are composed of the phase zero "Mission analysis", phase A "Feasibility" phase B "preliminary definition" and phases for the product consolidation (which are not in the scope of this project). The structure and steps are further discussed in chapter 2.

1.4.Aerospace research and Satellite technologies development in Colombia

The space research and development in South America is reflected in each country in different ways, from having no experience and lack of support to having a space agency in Brazil "*Agência Espacial Brasileira*" and the improvement in the laws regarding aerospace as a case from Argentina with the National Commission of Aerospace Activities "*Comision Nacional de Actividades Aeroespaciales*" (CONAE).

The Colombian government throughout the National Planning Department (DNP) has implemented a similar commission in charge of the aerospace research, observation and navigation named "*Comision Colombiana del Espacio".*As baseline of the mission research, it was necessary to take as reference previous researches in the Space field in Colombia and it was found that:

> *"El sector satelital es un componente clave del ecosistema digital, como plataforma para la explotación de datos masivos y un instrumento para el desarrollo económico y social de los países (OCDE, 2014) (OCDE, 2016)."*

This meaning "The satellite Industry is a key component of the digital ecosystem, as a platform for the massive data exploitation and a tool for the economic and the social development of the countries (OCDE, 2014) (OCDE, 2016)."[1] In this plan for the development of satellite, technologies proved the need of a strong research regarding space and satellite techs from conceptual design to building prototypes and industry.

[1] Free translation

1.5.Mission Types

In the Space mission there are different types and they are used in accordance to achieve the mission objectives, these mission types vary from remote sensing, telecommunications, space exploration and earth observation.
The importance of these mission are the needs of studying the behavior of the climate changes, telecommunications, defense, fires detection, population and among with a variety of sectors where the mission type can be focused on as established on reference [8].

This document named "Satco1" as mentioned in the objectives is a research focused on the Earth Observation of the Colombian Earth Surface; this information about the Earth Observation is explained in section 1.6 and shall be the reference for setting the types of requirements for the Colombian Earth Observation context, explained in section 1.8.

1.6.Earth Observation & remote sensing.

The Earth Observation missions are designed to improve our understanding on the Earth and one way to perform this is through the remote sensing. The use cutting-edge space technologies to learn more about the interactions between the atmosphere, biosphere, hydrosphere, cryosphere and Earth's interior is a very fundamental factor when it comes to the Earth observation [1]. These interactions are essential to understanding the behavior of the Earth as a system likewise, the understanding of the weather, climate changes and behaviors are essential for the earth observation and remote sensing.
According to the Ocean service page [42], the remote sensing is the science of obtaining information about objects or areas from a distance, typically from aircraft or satellites. Remote sensors collect data by detecting the energy that is reflected from Earth and these sensors can be on satellites or mounted on aircraft. Likewise, the remote sensing types are two "passive" and "active". The Active remote sensing is the one which instrument emits energy actively rather than collecting information about light energy from another source (the sun) [20] as it happens in the "passive" there methods are explained in section 1.7 "remote sensing methods"

1.7.Remote sensing Methods

In the remote sensing as explained in section 1.5 and according the NASA earth observatory [19], there are two types, the passive and active, in one hand, the passive instruments (or methods) detect natural energy that is reflected or emitted from the observed scene. Passive instruments sense only radiation emitted by the object being viewed or reflected by the object from a source other than the instrument. Reflected sunlight is the most common external source of radiation sensed by passive instruments. Scientists use a variety of passive remote sensors such as the radiometer, imaging radiometer, spectrometer and the spectroradiometer, see section 1.7.1 to 1.7.4 for each explanation.

1.7.1. ***Radiometer**:* An instrument that quantitatively measures the intensity of electromagnetic radiation in some band of wavelengths in the spectrum).

1.7.2. ***Imaging radiometer**:* A radiometer that includes a scanning capability to provide a two-dimensional array of pixels from which an image may be produced is called an imaging radiometer.

1.7.3. ***Spectrometer:*** A device designed to detect, measure, and analyze the spectral content of the incident electromagnetic radiation is called a spectrometer.

1.7.4. ***Spectroradiometer:*** A radiometer that can measure the intensity of radiation in multiple wavelength bands (i.e., multispectral).

On the other hand, there is the active instruments (or methods) which are those that provide their own energy (electromagnetic radiation) to illuminate the object or scene they observe. They send a pulse of energy from the sensor to the object and then receive the radiation that is reflected or backscattered from that object. Scientists use many different types of active remote sensors, such as the radar (Radio Detection and Ranging), scatterometer, LIDAR (Light Detection and Ranging) and laser altimeter [19]. See section 1.7.5 to 1.78 for explanation

1.7.5. ***Radar (Radio Detection and Ranging):*** A radar uses a transmitter operating at either radio or microwave frequencies to emit electromagnetic radiation and a directional antenna. Likewise, as the receiver to measure, the time of arrival of reflected or backscattered pulses of radiation from distant objects. Distance to the object can be determined since electromagnetic radiation propagates at the speed of light.

1.7.6. ***Scatterometer:*** A scatterometer is a high frequency microwave radar designed specifically to measure backscattered radiation.

1.7.7. ***Lidar:*** A lidar uses a laser (light amplification by stimulated emission of radiation) to transmit a light pulse and a receiver with sensitive detectors to measure the backscattered or reflected light.

1.7.8. ***Laser altimeter:*** A laser altimeter uses a lidar (see above) to measure the height of the instrument platform above the surface. By independently knowing the height of the platform with respect to the mean Earth's surface, the topography of the underlying surface can be determined.

As a result of this information gathered from the NASA earth observatory [19], this gets to the resolution that the active instruments provide their own energy to illuminate the observation point and the passive) detect natural energy that is reflected or emitted from the observed point.

1.8.Colombian Earth Observation- General Requirements

In the Colombian Earth observation, there are different types of requirements established, based on the Colombian Earth Observation and needs such as land use and growth, environment, defense and health. Likewise, the Stakeholder (see definition section) requirements are priority ever since they determine the needs that they want to solve and support. Some of these requirements are:

- Functional and Physical requirements: These requirements are based on the functional attributes which are the "characteristics" defined using the customer and user needs. Likewise, the requirements are named "functional" after the definition of the main functions that the systems shall perform and "physical" for the type of physical system affected by the requirement [18].
- Operational Requirements: they are the requirements, which determine how the system operates and how users interact with it to achieve its broad objectives.
- Quantifiable requirements: This process is used to give a "quantity" to the requirements already defined (functional/physical or operational). This quantity is can be number of days, revolutions, revisit, time, altitude as an example; the reason to perform this process is to give a more exact requirement for the systems and to be able to accomplish them in further detailed design [18].

1.9.Quality Function Deployment (QFD).

As part of the systematically development of the requirements of the Space Mission, there is a process and set of tools used to effectively define customer/user requirements and convert them into detailed engineering specifications [43]. The QFD derives from three Japanese words or characters meaning (1) quality or features, (2) function or mechanization, and (3) deployment or evaluation [8]. Hence, the QFD is used to connect customer needs or requirements to technical attributes or requirements and the most common tool to use at first instance is the "House of Quality".

1.9.1 House of Quality: According to the Quality-One international, reference [43], the House of Quality is an effective tool used to translate the customer wants and needs into product or service design characteristics utilizing a relationship matrix. It is usually the first matrix used in the QFD process for the graphical way to show and order the "what's" (what is needed) and how's (how it is going to be solved or what solves this.

1.10. Earth Satellite Orbits

For the development of the requirements and the other sections involved on the space project, it

is important to understand that the type of satellite orbits are available and proper to be used as for the accomplishment of the orbital parameters.
There are three mainly types of orbits used on the Earth as for navigation, observation, sensing, etc. Those are the High Earth Orbit, medium Earth Orbit and a Low Earth Orbit along with the special orbits “polar orbits” and “Sun-synchronous orbits” [18].

It is needed to define the orbit that suits to the main objective of the mission and in this case for the observation of the Colombian earth surface between a High Earth Orbit, medium Earth Orbit and a Low Earth Orbit. Using a High Earth Orbit may work if this project was focus on climate observation, this orbit is functional because it gets to a “sweet spot” [9]. Where the orbit matches to the Earth’s rotation meaning that the satellite will be at the same spot all the time as the earth rotates which is perfect for verifying the climate changes. This Orbit could also work for a steady and continuous observation, however, because it is in a long distance the quality of the observation is not detailed to the earth surface and close areas, which is something this project wants to achieve.

A **Medium Earth Orbit** is precise and works for long altitude earth observation otherwise, it is not what this project wants to achieve, in that case the other option and the best one that there is left is the Low Earth Orbit and there is where a sun-synchronous orbit remains as the best option for this project.

On the other hand, the special orbit, the **Sun-synchronous orbit** (which is a special orbit of the **Lowe Earth Orbit**). Just as the **geosynchronous** satellites of having different characteristics such as having a sweet spot over the equator that lets them stay over one spot on Earth, the polar-orbiting satellites have a sweet spot that allows them to stay in one time [18].
Hence, this orbit is a Sun-synchronous orbit, which means that whenever and wherever the satellite crosses the equator, the local solar time on the ground is always the same. For the Terra satellite for example, it is always about 10:30 in the morning when the satellite crosses the equator in Brazil [5].
Likewise, when the satellite comes around the Earth in its next overpass about 99 minutes later, it crosses over the equator in Ecuador or Colombia at about 10:30 local time [5]. In this case, many items/parameters have to be taken like orbital inclination, satellite height, period, etc. The systems have to be designed having into account that because of the proximity of this orbit to the earth gravity, eventually the satellite will be attracted to the Earth, hence a system needs to be included so the adjustments can maintain the satellite in the Sun-synchronous orbit.

As part of the orbit selection, reckoning time is one important factor for understanding the orbits behavior and orbital parameters or elements and this is explained in section 1.10.1

1.11. Orbit Altitude

As part of the orbit selection, and reckoning the type of Orbit that is used for the Space Mission, the Orbit altitude is going to be needed to be defined as for the customer/user requirements

accomplishment, along with the Orbital parameters, as defined for a Low Earth Orbit, the altitude ranges between 500 km and 1000 km.
It is needs to understand that under 500 km, the drag produced by the earth is going to affect the orbit mission, and over 1000 km, the quality, range and observing characteristics are affected [18]. These ranges are baseline for a Selection of other orbital parameters (Eccentricity, anomaly, time, etc.) using the Kepler's equation.

1.11.1. Kepler's equation: is an equation that describes the relationship between time and place for objects in an elliptic orbit under the influence of gravity and with this equation, different orbital parameters can be defined Eccentricity, anomaly, time or even the altitude, depending on the selection of orbits and requirements [44].

1.12. Orbital Elements/parameters

According to the Cosmos. ESA page [45], the conic functions only give the path of the spacecraft in the plane of the given part of the orbit. They tell nothing about the orientation of the orbital plane in space. If it was desired to define the orbit completely, it is needed to use a set of parameters called the Classical Orbital Elements, which can be specified for each phase of the orbit and are usually referenced to a particular time, or epoch, and frame of reference. In addition, in accordance with the SS-O design handbook [18] and the Cosmos. ESA page [45], these orbital elements and definitions are the next:

- Mean Distance (a) - the semi-major axis of the orbit measured in Astronomical Units (1 AU = 149.59787 million km);
- Inclination (i) - the angle between the ecliptic plane and the plane of the orbit;
- Eccentricity (e) - the eccentricity of the conic (0=circle, <1=ellipse, 1= parabola, >1=hyperbola) that describes the orbit;
- Longitude of the Ascending Node (Omega) - the position in the orbit where the path of the spacecraft passes through the ecliptic plane, from below the plane to above the plane, measured from the vernal equinox (1st point of Aries);
- Argument of Perihelion (w) - the angle in the plane of the orbit from the ascending node to the point where the spacecraft is closest to the Sun;
- Mean Anomaly (M) - angle increasing uniformly with time by 360 degrees per orbital period from 0 at perihelion;
- True Anomaly (TA) - the actual angle between the spacecraft position and the perihelion as seen from the Sun. This angle increases non-uniformly with time, changing most rapidly at perihelion.

In next chapters these orbital characteristic shall be shown along with the simulation in a Satellite took kit program (see sect. 1.13) with the aim of understanding the way all these parts of the conceptual design can synchronized be reflected.

1.13. Satellite Tool Kit

According to the AGI web page (developer of the tool) [46], they describe the STK as the provider of an inclusive modeling environment used worldwide by public and private sector organizations to model complex land, sea, air, or space systems and evaluate their performance in real or simulated time. STK supports timely decision-making in a mission context about complex, inter-related systems; and can be applied at any stage in their lifecycle: from planning and design to training and operations.

1.14. SatCo1

SatCo1 is the name assigned for this mission design for the Colombian Earth Observation adjusted to the Customer/user needs as explained in chapter 2.

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CHAPTER 2 – MISSION ANALYSIS AND DESIGN-MISSION DEFINITION REVIEW (MDR)

According to the space mission Analysis and Design (SMAD) [8]: a Space mission analysis and design begins with one or more broad objectives and constraints and then proceeds to define a space system that will meet them at the lowest possible cost. This definition directs to a systemically concepts baseline which shall allow the proper research for the Colombian Earth Observation mission design.

The space mission Analysis and Design (SMAD) is a process that evaluates every stage needed for the Space Mission Set-up, having into account different issues such as the Mission objectives, characteristics, evaluation and requirements based on the space mission Analysis and Design book from Wiley J. Larson and James R. Wertz [8].

For the analysis and design, this project will also be based on the ECCS-E-ST-10C [16] "System engineering general requirements"-Conceptual design (phase zero, A and B) as discussed in the Chapter 1 section 1.3. The structure of these tasks-phases are going to be reviewed in the next chapters where it is intended to achieve the next tasks:

- The Mission design review (**MDR**) - Chapter **2.**

- Preliminary requirements review (**PRR**) - Chapter **3.**

- Systems requirements review (**SRR**) – Chapter **4.**

- As an approach to the Preliminary design review (**PDR**), the Orbit mission simulation will be reviewed along with its parameters and/or calculous- Chapter **5.**

This mission is named after satco1 as stated in chapter 1. Sec.1.14, which stands for the Colombian Earth observation conceptual design number 1 and will be developed along with the core research chapters 2, 3, 4 and 5.
In this chapter, the mission design is reviewed as for the preliminary definitions, characteristics and evaluation, which shall allow having a baseline for the next chapters. This review is represented in the diagram 2.1 "SMAD process for the mission design review", in accordance with the SMAD process, where the information gathered in diagram 2.1 is taken from and it summarizes an approach to the space mission analysis and design process.
Space missions range widely from communications, to planetary exploration, to proposals for space manufacturing, to burial in space. See diagram 2.1 as shown below:

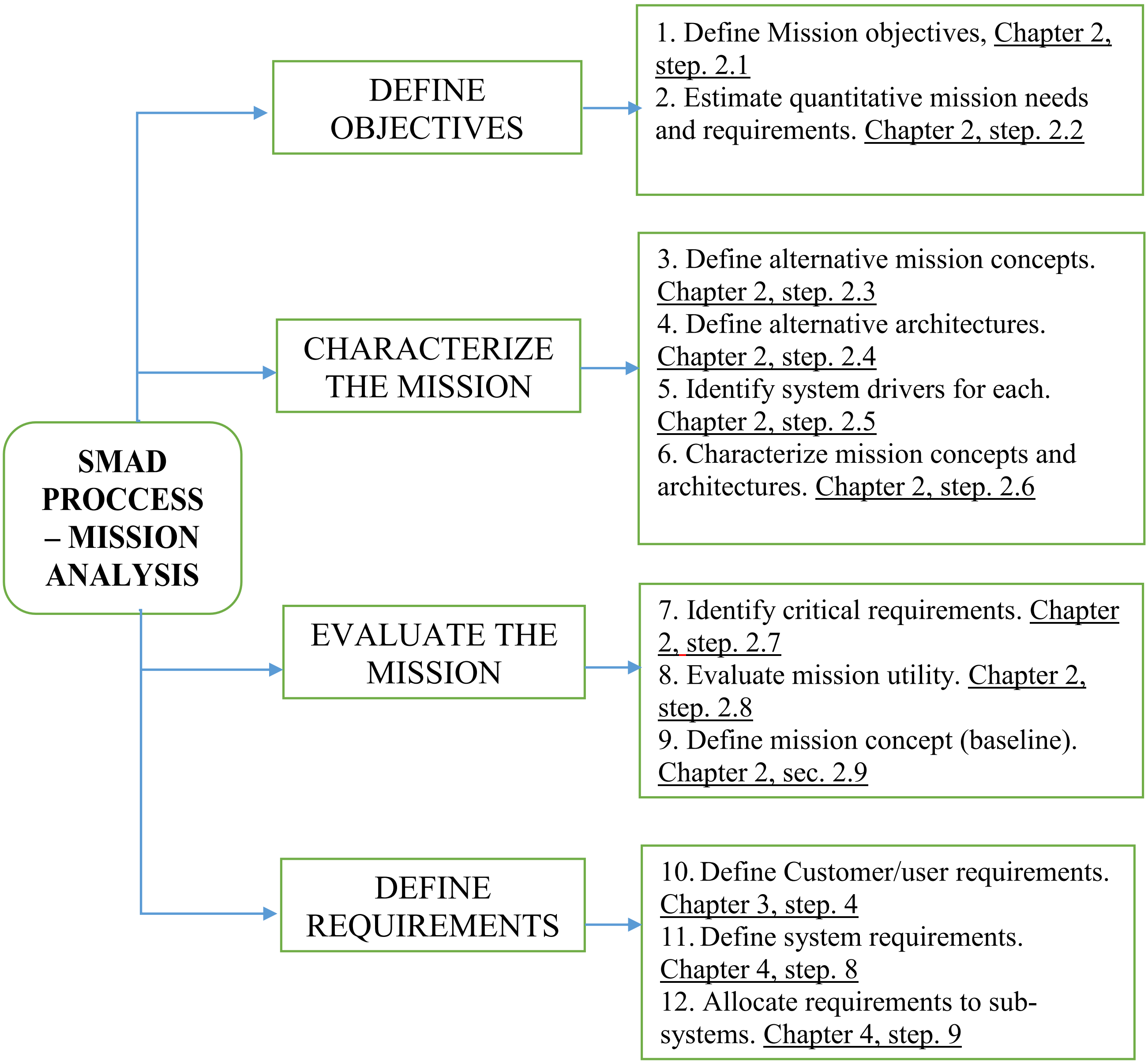

Diagram 2.1. SMAD process for the mission design review, Sub-steps taken from SMAD book, chapter 1 to 3 and ECCS-E-ST-10C "System engineering general requirements" [16].

2.1. Definition of Mission Objectives

In accordance to the SMAD book [8], the first step in analyzing and designing a space mission is to define mission objectives: the broad goals, which the system must achieve to be productive. The first part is defining the mission objectives as shown in table 2.1 "Mission Objectives". This objectives and constraints shall be a baseline for the customer/user requirements and needs establishing and it shall be further discussed in chapter 3 and 4.

Table 2.1 Mission Objectives, mission objectives that shall affect the customer/user objectives and scope. Information based on the Colombian Earth Observation Magazine [13].

SatCo1 Mission Objectives
Primary Objective: Observe and monitor the Earth throughout the Colombian surface, in near real time
Secondary Objectives: Observe urban and rural areas. Therefore, different topics can be checked such as Urban growth (buildings, streets, highways, etc.) deforestation, etc. Allow the access to data regarding to High quality Images in different areas. Collect images and keep track of older images at the same spot so changes can be trade, noticed, studied and researched.

2.2. Estimate quantitative mission needs and requirements.

As the next part of the mission objectives definition (Sub-step 2.2), it is needed to define the factors and preliminary requirements (functional and operational) along with the constraints that may affect the customer/user requirements stated in the second part of this step in the table 2.2 "Functional, Operational requirements and constraints". In accordance with the SMAD book, section 1.4 [8], having defined the broad objectives that the space mission is to achieve, it is needed to transform them into preliminary sets of numerical requirements and constraints on the space mission's performance and operation.
Based on the Mission Objectives, the *Functional*, *Operational* and *constraints* are established, hence, the requirements and factors which typically impact the requirement for Each are stated in the next tables using as reference SMAD [8].. Thus, the Mission Objectives can be evaluated later on with the Evaluation of the Mission and the Client's Requirements.

Table 2.2 Functional, Operational requirements and constraints, based on the SMAD book section 1.3 [8], definition of objectives, as for the preliminary requirements constraints. Qualified as preliminary requirements/constraints further studied in chapter 3 and complied in table 4.8 "Requirements table summary" form chapter 4.

FUNCTIONAL	
Requirement	**Factors which Typically Impact the Requirement**
Performance **(PFR01)**	Payload, Orbit, Prototype, Design, Structure
High quality images acquisition **(PFR02)**	Payload selection and its design location
Field of view **(PFR03)**	Commands definition, sensing system, computing, proper data set-up, payload
Responsiveness **(PFR04)**	Computer processing, Software, sensors
Orbit synchronization **(PFR05)**	Propulsion, data receiving, controller, launch

OPERATIONAL	
Requirement	**Factors which Typically Impact the Requirement**
Data managing, collecting and transfer **(POR01)**	Computer, communications, sensors
Duration **(POR02)**	Materials, payload, Orbit, Space debris
Command and controlling **(POR03)**	Earth receiving data architecture
Availability **(POR04)**	Materials endurance and life limits
Survivability **(POR05)**	Orbit, propulsion, Source of electrical power
CONSTRAINTS	
Constraint	**Factors which Typically Impact the Requirement**
Cost **(PCO01)**	Size, materials, payload, design
Regulations **(PCO02)**	law and policy
Sponsoring **(PCO03)**	Owner of the Mission
Design modeling program **(PCO04)**	License, Designer, Design concepts
Launch (most optional Launch from French Guiana) **(PCO05)**	Size, location, schedule
Environment **(PCO06)**	Payload, materials, propulsion system, design

2.3. Define alternative mission concepts.

The broad mission concept is the most fundamental statement of how the mission will work-that is, how it gets its data or carries out the mission to satisfy the end user's needs [8]. In this step, these elements and definitions are based on the FireSat elements of the mission concept of operations from de SMAD section 2.1 [8] and it is going to be adjusted to the SatCo1 mission concepts as in accordance to the standard ECCS-E-ST-10C [16] for the mission definition review, phase zero, this is shown in table 2.3.

The elements concept taken from the SMAD section 2.1 are listed below and shall contribute to the Concept definition of the Mission as shown in table 2.3 "SatCo1 Definition of Element application"

Data Delivery: The data delivery concept is about how the mission and housekeeping data are generated or collected, distributed and used.

Communications Architecture: The communications Architecture is how the various components of the system "exchange information" to each other.

Tasking, scheduling and control: The definition of the tasking, scheduling and control is about how the system decides what to do in the long term and short term.

Mission Timeline: For the mission timeline, it is the overall schedule for planning, building, deployment, operations, replacement and end of life.

Table 2.3 SatCo1 Definition of Element application, based on the SMAD book section 1.3 [8], definition of objectives, as for the preliminary requirements constraints.

Element	SatCo1 Definition of Element application
Data Delivery **(ELE01)**	All data collection is going to be received in an earth data management station and the telecommunication system.
Communications Architecture **(ELE02)**	A Hardware and sensors telecommunication system
Tasking, scheduling and command **(ELE03)**	Earth receiving data station, antennas and sensors integrated, definition of places where the Satellite is going to be focused on by Week
Mission Timeline **(ELE04)**	The SatCo1 after having all the tests and results in accordance to the project and client requirements is going be prepared for the launch.

2.4. Define alternative architectures.

According to the SMAD book [8], a mission architecture consists of a mission concept plus a specific set of options for the mission elements definition. The table 2.4 "Alternatives for mission elements" stands for the mission elements in the left column (1), the alternative architectures in the middle column (2) and the operation/area affected (3) as shown below.

Table 2.4 Alternatives for mission elements, based on the SMAD book section 2.2 [8], common alternatives for mission elements.

Alternatives for mission elements		
Mission Element	**Alternative**	**Operation/Area**
Mission concept **(MIE01)**	Ground commanding, systematical process/ automated processing	Data delivery Tasking
Payload **(MIE02)**	Aperture and sensing methods	Size- optical sensing
Orbit **(MIE03)**	Low-Earth orbits, mid altitude and Geosynchronous -- SS-O and frozen -- 0°, 28.5°, 57", 63.4°, 90°, 98"	Altitude ------------------------- Special orbits ------------------------- Inclination
Ground system **(MIE04)**	French Guyana and dedicated control center ever since it is the closest station available and different space launches are performed there from the EU, which makes it more available in different periods of the year.*	Dedicated to Ground system command.
Communications architecture **(MIE05)**	Single, or multiple ground stations, different users commanding and data achievement.	Timeliness

Alternatives for mission elements		
Mission Element	**Alternative**	**Operation/Area**
Mission operations **(MIE06)**	Full ground command and control, partial autonomy or full autonomy	Autonomy level

*Future Ground System can be implemented in Colombia when developing Space ground facilities

2.5. Identify system drivers for each

For the SMAD definition System drivers are the principal mission parameters or characteristics, which influence performance, cost, risk, or schedule and which, the user or designer can control [8]. There is need to have a step by step in order to identify system drivers and those are:

1. Identify the area of interest: To choose between the areas of performance, cost, risk or schedule
2. Identify parameters, which measure the area of interest: In this section, it is needed to define numerical parameters, which measure the identified area of interest.
3. Develop First-Order Algorithms: To develop a formula or algorithm to express the first-order estimate value for the value of the parameter identified in the previous steps.

The above sub-steps are adjusted to the mission definition review of this chapter and it is shown below, see table 2.5:

Table 2.5 Identifying system drivers, based on the SMAD book section 2.3 [8], common system drivers.

IDENTIFYING SYSTEM DRIVERS		
1. Driver	**2. Parameters**	**3. First order Algorithms**
Power **(DRI01)** Date rate **(DRI02)** Communications **(DRI03)** Coverage **(DRI04)** Operations **(DRI05)** Payload **(DRI06)** Orbit **(DRI07)** Altitude **(DRI08)**	A) Meet overall mission objectives B) Feasibility (technically) C) Risk acceptance D) Schedule and budget	1. Link budget 2. Mapping and pointing budget 3. Orbits parameters equations – chapter 5. 4. Altitude selection- Chapter 4. 5. Payload parameters, optical and remote sensing- chapter 3 and 4.

2.6. Characterize mission concepts and architectures

Once the alternative mission concepts, architectures and system drivers. The mission concepts must be further defined in enough detail to allow meaningful evaluations of effectiveness [8]. This characterization process is represented in a sub step by step and it is represented in the table 2.6 “Concept characterization Process,” this information taken from the SMAD book [8]. The left column (1) is for the step and second column (2) is for the result/ where discussed or where it will be reviewed.

The table 2.5 is also intend to have a small but precise baseline of the concept characterization and it will be further reviewed one by one chapters 3, 4 and 5. This characterization will also support the mission drivers and parameters, which will be part of the requirements baseline discussed in chapter 4 and 5 of this document.

Table 2.6 Concept characterization Process, based on the SMAD book section 2.4 [8], characterizing the mission architecture.

Concept characterization Process	
Sub-Step	**Result/where discussed**
A Define the preliminary mission concept	Discussed already in step 2.3.
B Define the subject characteristics	Summary of main characteristics of space mission subjects, taken form table 2-11 [8], adjusted to the SatCo1 mission: 1. Quantity 2. Location or range (Defined in customer/user requirements, chapter 4) 3. Transmitter 4. Receiver 5. Frequency and bandwidth (Defined in customer/user requirements, chapter 4) 6. Duty cycle.
C Determine the orbit or constellation characteristics	Characteristics of orbit constellation are based on [8] and [18], these parameters will be reviewed throughout chapter 3, 4 and finally summarized in chapter 5: 1. Altitude 2. Inclination 3. Eccentricity 4. argument of perigee
D Determine payload size and performance	Characteristics of payload are based on [8] and [18], these parameters are reference for a future preliminary design and they aren't contemplated in this project's scope: 1. Physical parameters (dimensions and mass)

Concept characterization Process	
Sub-Step	**Result/where discussed**
	2. Viewing and pointing 3. Electrical power (power and average peak power) 4. Telemetry and commands 5. Thermal control
E Select the mission operations approach: - Communications architecture - Operations - Ground system	Characteristics are based on [8] and [18], these parameters are reference for a future preliminary design and they aren't contemplated in this project's scope: - Communications architecture: Number and distribution of ground stations Relay satellites used - Operations: Required data handling Using of existing dedicated facilities - Ground system: Level of automation Software lines of code to be created
F Design the spacecraft bus to meet payload, orbit, and communications requirements	1. Functional block diagram (chapter 3.) 2. System parameters (chapter 4)

2.7 Identify critical requirements.

In this section, it is needed to establish the "critical requirements", which are those that dominate the space mission's overall design and, therefore, most strongly affect performance and cost [8], these critical requirements are not the last requirements, otherwise, and they are an approach to the customer/user requirements and the mission accomplishment.

For the SatCo1, the critical requirements are: *to achieve an earth observation for the Colombian Earth surface in different weather conditions for different applications*[2] *such as the defense, environmental control and population.*

[2] These are preliminary applications as for the main critical requirements achievement. The research of areas of application are exposed in chapter 3.

Likewise, based on the SMAD book [8] and the SatCo1 objectives, the next critical requirements will affect the mission design:

- Resolution: Affects the instrument size, altitude, command and control
- Mapping accuracy: Affects the altitude control, payload precision and data processing.
- Coverage and response time: affect the altitude, inclination, communications and architecture.

2.8 Evaluate mission utility

For the mission utility form this section, the concept has to be understood as the process of quantifying the system parameters and the resulting performance [8]. This mission utility process is used to provide information for decision-making, and provide feedback on the system design. These are the phases where this project emphasizes, in accordance with the mission objectives, this evaluation is performed by a analysis and/or simulation, using the SMAD book, table 3-6, the analysis performed by calculus or data established research and the simulation made in Satellite tool kit [33] (STK).

The next table as stated before stands for the mission utility process and it shall include the performance parameters for the mission accomplishment and it will be developed in chapter 5 "Mission design- analysis and simulation" using this table as baseline, see table 2.7 "Performance parameters- mission utility".

Table 2.7 Performance Parameters for SatCo1-Mission utility, based on the SMAD book table 3-6 [8], Representative performance parameters

PERFORMANCE PARAMETERS FOR SATCO1		
NºC.	**Performance parameter**	**Ho Determined /Where discussed**
1.	Minimum coverage- Scale **(PEP01)**	Analysis (chapter 4 &5)
2.	Mean time between observations **(PEP01)**	Analysis (chapter 5)
3.	Revisit (time to point same location) **(PEP01)**	Analysis/simulation (Chapter 4 & 5)
4.	Orbital parameters (altitude, perigee, apogee) **(PEP01)**	Analysis/simulation (chapter 4 & 5)
5.	Ground position knowledge **(PEP01)**	Simulation (Chapter 5)
6.	Resolution **(PEP01)**	Analysis (chapter 4)

2.9 Define mission concept (baseline).

This is the final step on the mission evaluation and here it is intended to define different factors to allow knowing whether to proceed with it or not. Hence, this baseline is going to allow a decision making for proceeding or not and it will affect the next chapters for the Preliminary requirements review, systems requirements review and the chapter 5 “Mission Design- Analysis and simulation”.

The Mission Evaluation is based on the information gathered throughout this chapter; the next table shows some aspects for the Mission Concept Selection as the baseline (go/no-go decision) [8] that needs to be taken into account for the mission development, see table 2.8 “Mission concept selection- Go/no go decision”

Table 2.8 - Mission concept selection- Go/no go decision, based on the SMAD book section 3.4 [8], Mission concept selection.

MISSION CONCEPT SELECTION- GO/NO GO DECISION	
Factor	**SatCo1 decision**
Is it technically feasible?	Mission requires standard materials, design, parts and payload, with the proper engineering design and analysis this can be performed. **(DEC01)**
Is the level of risk acceptable?	This Mission is based on other satellite Earth Observation Missions where the risks as in the design and implementation is taken into account. **(DEC02)**
Are the schedule and budget within the established constraints?	The schedule and budget depend on the sponsor and client of the project so this mission can be achieved. **(DEC03)**
Does the mission meet the political objectives?	This mission is under the objectives for the Colombian Satellite technologies advances as mentioned in part 2. Of this document. **(DEC04)**

This go-no go analysis finds that the mission concepts from this section and chapter 1 matches to the project scope and the decision for this part is to continue with the next chapters (refer to chapter 3 “Preliminary Requirements Review”).
Likewise, as explained before, the information gathered above from step 2.1 to step 2-9 allows having a mission definition review and concept baseline, and makes part of the core of this project research that will be further reviewed in the next chapters (3,4 and five), conclusions of this section will be further discussed.

CHAPTER 3 - PRELIMINARY REQUIREMENTS REVIEW (PRR)

In order to do any analysis or design for the Conceptual Design and Systems engineering process, the requirements have to be settled, requirements such as the User/customer, technical, physical and systems requirements. This project uses as reference the system engineering general requirements standard ECSS-E-ST-1[16], which emphasizes in the importance of defining and developing requirements as the front-end process for system design, development and deployment.

The process of developing requirements shall systematically be performed step by step, which are going to be explained in chapter 3 and 4 (recalling that they are linked to each other). Likewise, for chapters 3 and 4, the preliminary and systems requirements respectively are going to be reviewed using as a guidance the Space mission analysis and design (SMAD) [8].

The next diagram (diagram 3.1) is a summary for developing a requirements baseline with nine steps (as the reference steps from the SMAD book [8]). In the chapter 1, the Customer/user, objectives, constraints and needs are going to be reviewed (Steps 1 to 4). Afterwards from the architecture expressed since the step five, the systems functional requirements and characteristics shall be decomposed in lower levels; this is going to be shown in the next chapter (Chapter 4. Systems requirements review SRR, steps 5 to 9).

All steps shall be evaluated one by one systematically in this project using as baseline the references form the Earth Observation Magazine [13]. The Space Mission Analysis and Design book [8] and A-B-Cs of Sun-Synchronous Orbit Mission Design [18], this information is shown from step one to step nine as written bellow, see diagram 3.1 "Steps to Developing a Requirements Baseline".

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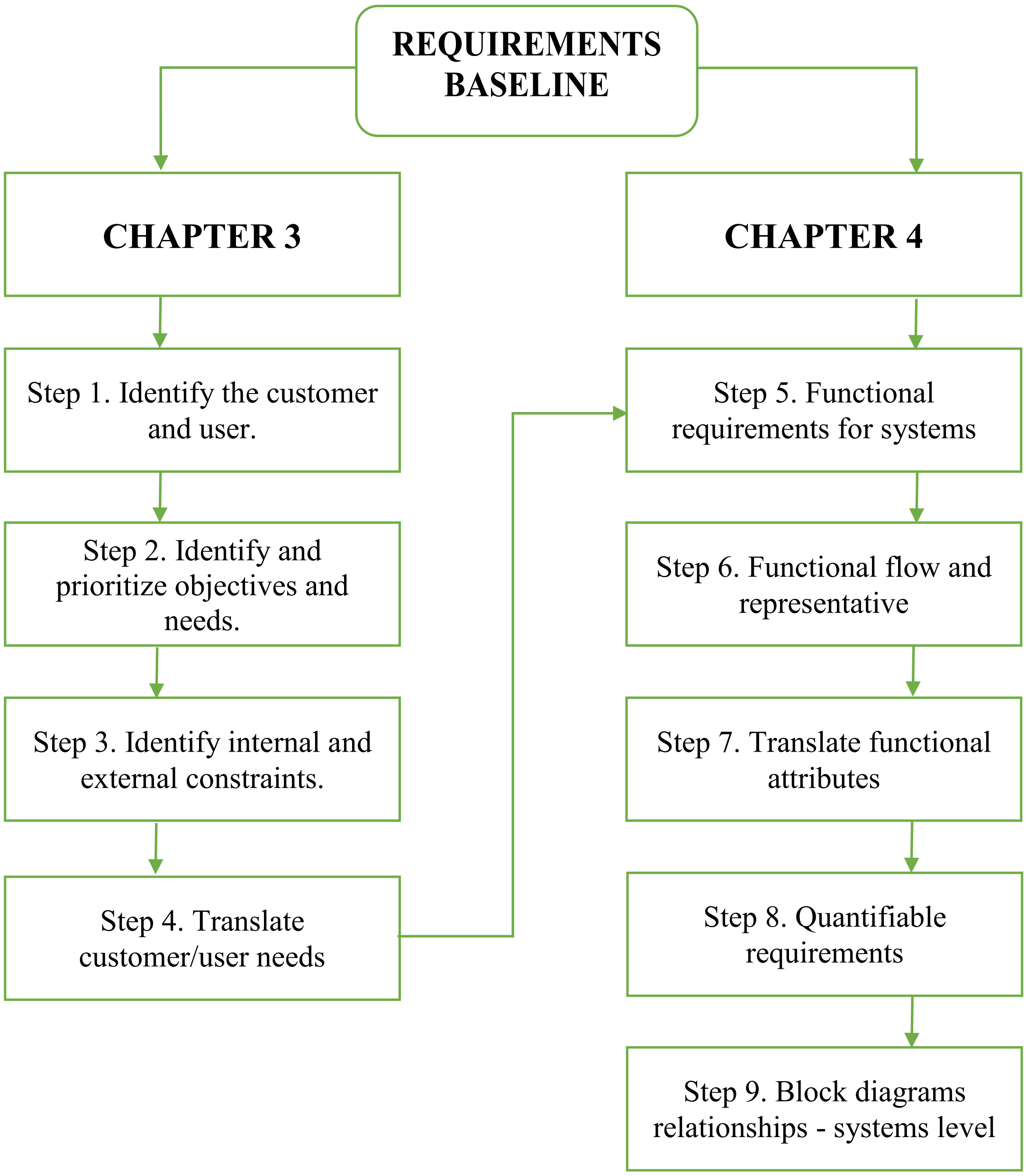

Diagram 3.1 Steps to Developing a Requirements Baseline.
Source: Author

<u>Step 1 Identify the Customer and User</u>

In this step, the customer and user of the product/service is going to be identified, as a customer may be a procuring agent but not the ultimate user and both must be understood. The main difference between users and customers is that "customers usually pay for the service, otherwise, the users receive the services that other pays for" [8].

All requirements must begin with succinct but well-defined user and customer mission needs, focusing on the critical functional and operational requirements, without unnecessarily constraining or dictating the design [8].
The next thing to have into account is the possible solution (s) of this mission shall be focused on the Colombian space programs and observation of the earth surface. Hence, the research gets

to the conclusion that the customer of the project/mission is the one that shall financially support it, whereas the user makes part of the project since its conception until having the final product. The user shall support the mission as first part by defining the critical functional and operational requirements, and will be reviewed at the beginning of project with the developers, operators and users.

As explained in the chapter 1. Section 1.4 The National Planning department (DNP) has the objectives of the development of the Space research in their National development plans (DNP), reference [2] and [6]. Hence, having this into account and remembering that the project requires a customer that may be interested in the Earth observation for the Colombian surface, and following the legal statements, this project gets to the conclusion of defining the DNP as the desired customer.

The Colombian Commission for the Space (CCE) was created after the presidential decree, 2442 of 2006 as the representative section for the planning, organization, research and as stage for the gathering of institutional management about: Telecommunications, satellite navigation, Earth observation, astronautics, astronomy and aerospace medicine [13].

This commission is the focal point of the space matters and it works along with different entities such as the Defense Ministry, Civil Aeronautics and the DNP [13]. Being this not only a defense but also a civil purposes commission with the aim of gathering the Space research, ever since there is not a Space Agency established in Colombia yet.

As one of the functions of the CCE is the application of space technologies to improve the earth observation, to support the environmental management and to work as a guide for the proper resources usage [13]. Likewise, being an important baseline for the disasters prevention (forest fires, mudslides, avalanches, floods, etc.) and risks management. This project is based on the Earth observation of the Colombian surface next to its possible applications as mentioned in the chapter 2 with the mission objectives, and identifying that the CCS is the focal point of the Colombian Government for the space research. This project gets to the point of identifying the CCS as the principal and desired user of this project ever since this research is intended to accomplish important related objectives, see table 3.1 *"Summary for identifying the customer and user"*.

Table 3.1. Summary for identifying the customer and user. **Source: Author**

IDENTIFYING THE CUSTOMER AND USER	
CUSTOMER	**USER**
The National Planning Department (DNP)	The Colombian Commission for the Space (CCE)

Step 2 Identify and prioritize objectives and needs

Now that the customer and user have been identified, the customer/user objectives and needs require to be identified and prioritize as well, in this case the possible objectives and needs for the DNP [2] and the CCE [11] may be:

DNP objectives:

The DNP has a diverse variety of objectives but when it comes to space research, Earth Observation as reference [2] and [6], these main objectives are:

- To establish agreements with the Private sector and Academies for the development of satellite applications for the aeronautics field. Likewise, transportation means with a financed research plan.

- To promote a better scientific-technical capacity development in the country as a main factor for the creation of the National Agency of Space.

- To use means that look for enforcing the control of distribution and demand of fuel in the country borders using mechanisms of Satellite tracking.

- To enforce the information and communication technologies of (ICT) industry with satellite technologies (as one component of multiple ones in this enforcement).

CCE Objectives:

The CCE as the organism in charge of the Space research cooperation and it has the main objective to implement the Satellite development research program and the applications collaborating with different entities including civil and defense, concerning the Earth Observation – PHASE 1: Organization of the Satellite development research in Colombia project.

The specific objectives concerning this matter are:

- To establish mechanisms that contribute the investigation of satellite engineering in Colombia collaborating with different institutions in priority working topics of the Colombian Government.
- To Evaluate and propose alternatives for the appropriation of Satellite technologies for the Earth Observation.
- To formulate a technical viability to install a Colombian Satellite for the Earth Observation.
- To propose strategies to promote the technological development about the Earth Observation and the Country’s competitive levels in this field.
-

The information above has been taken from the CCE web page, reference [11], with these objectives; the needs are going to be evaluated as well to further get to the internal and external constraints (Step 3).

Prioritizing Customer/user objectives

For the mission to be accomplished the customer/user objectives need to be prioritized as the most feasible and accurate with this project scope, these objectives are shown in figure 3.1.
The next figure (figure 3.1) shows the Customer and User objectives complied in five levels as the most concerning objectives (top) as for the diverse possible applications of the satellite concerning the mission itself (down). Some of them are in the same level because in this project they are considered to be in the same level of importance. See figure 3.1 "*Customer/User objectives prioritized in levels*".

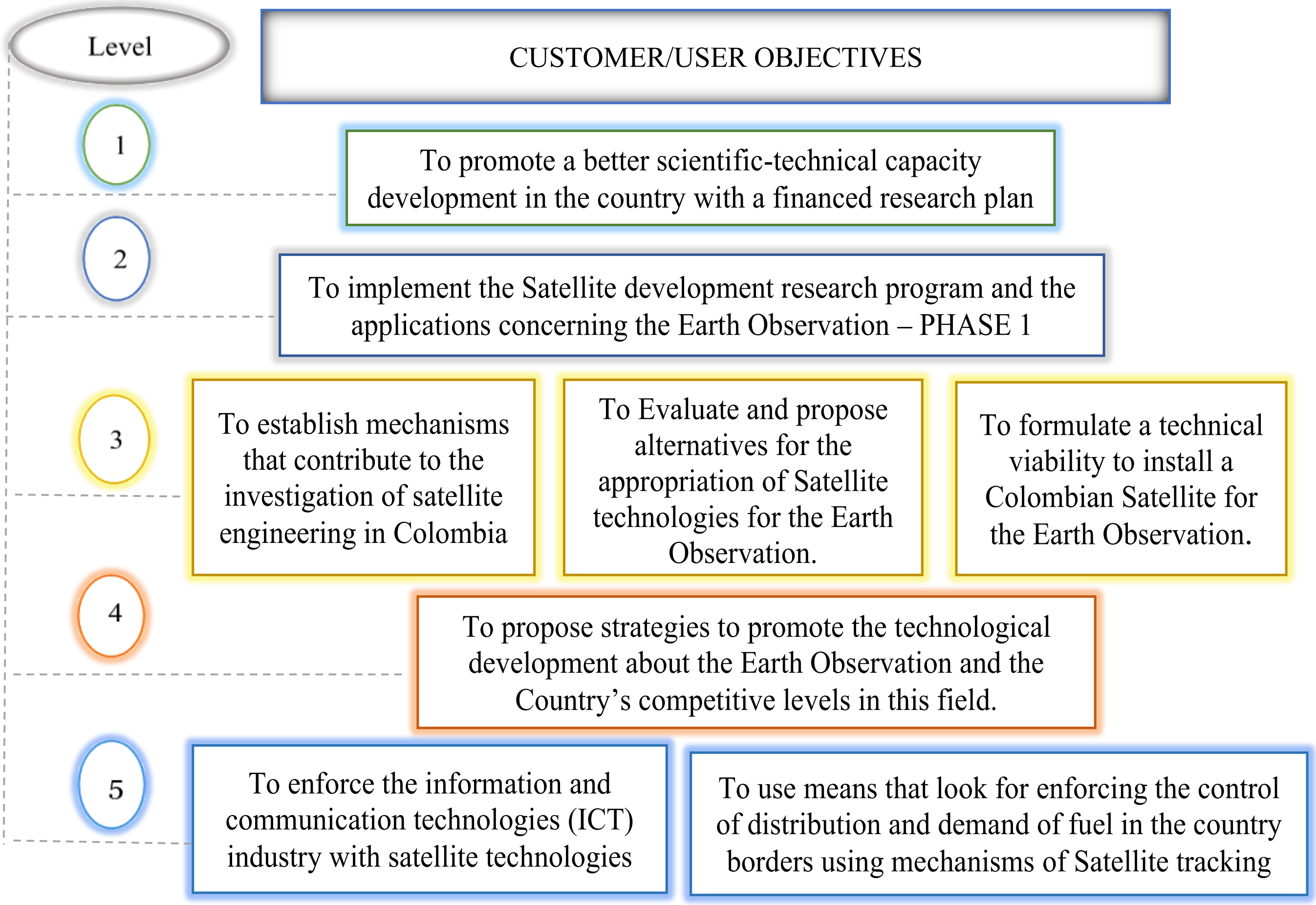

Figure 3.1. Customer/User objectives prioritized in levels.
Source: Author

DNP/CCE Needs:

As a correlated point for the CCE and DNP, the needs of the Colombian Earth Observation in different fields of usage require to be stated in this section being those the baseline for the technical requirements in the next steps.

Using as a reference a project made by the CCE exposed on the Earth Observation Magazine 2010 [13], the CCE group of applications elaborated a diagnosis of the needs and applications of the remote sensing in the country, with the objective of acquiring relevant information to determine the technical requirements for a Colombian Earth surface Observation satellite.
CCE based their project on different researches. Such as the information compiled of the IGAC (Geographic institute Agustín Codazzi) [14] and the SELPER (Latinoamierican Society of Specialists in Remote Perception and Geographic Systems Information) [15].

Their research has been compiled by means of surveys and workshops while consulting to different sectors in the Country about the usage of the data achieved with remote sensors, the needs, difficulties and requirements about technologies, processing and data applications.

As a result of the research, 36 areas were defined as main priorities for the remote sensing [13] with that information, these areas are the baseline for this section when identifying the technical requirements and needs are shown in figure 3.2. From reference [13] adapted into English language, see figure 3.2 “Areas of technologies application for the Earth Observation”.

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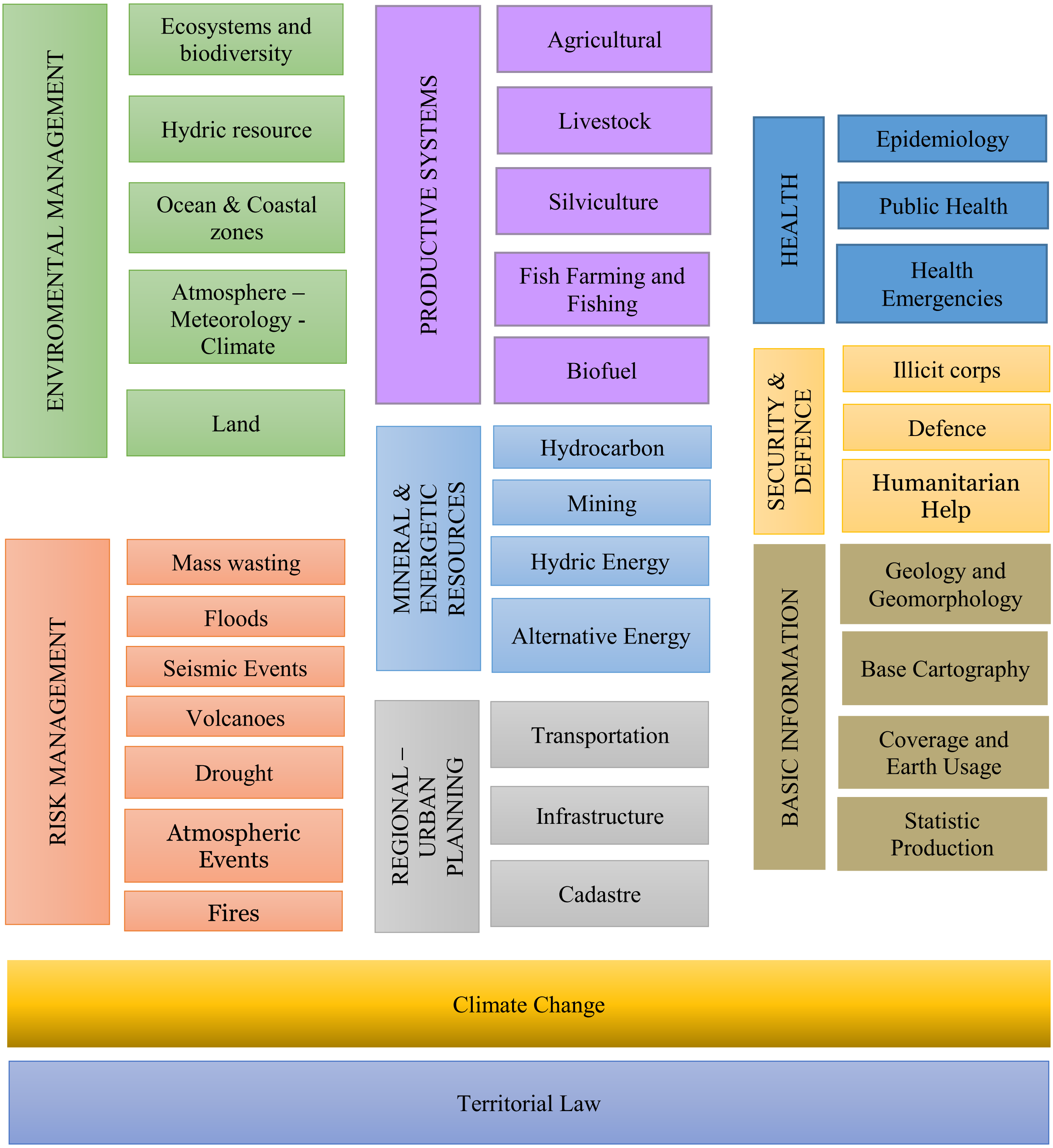

Figure 3.2. Areas of technologies application for the Earth Observation. From *"Programa de Investigación en Desarrollo Satelital y Aplicaciones en el Tema de Observación de la Tierra"*, reference [13] English language adaptation.

This diagnosis made clear some particular requirements in each area and sector in accordance with remote sensors needs (further discussed in step 7.1.1, chapter 5) likewise, it allowed getting to the conclusion that despite of the cloudiness issues in the country, it was considered a priority the usage of technologies of multispectral optical satellites [11].

The CCE research has gotten to the definition of the needs for the Colombian Earth observation satellite, they are going to be the baseline for the Customer/user needs statement, and development of this project as it suits to the Colombian Earth Observation matters and objectives set in the Chapter 2. See table 3.2 "Customer/User needs", as this information has been compiled from the satellite development and applications research, in regards to the Earth observation matters exposed in the Earth observation Magazine of the CCE [13].

Table 3.2. Customer/ User needs, *reference considered as the research exposed in the Earth Observation Magazine.* **Source: Author**

CUSTOMER/USER NEEDS	
NºC.	**Needs**
ND01.	To obtain right resolution images with costs reductions.
ND02.	To be able to count with periodic updated information.
ND03.	To have autonomy for the images capturing in priority places for emergency cases or other matters.
ND04.	To increase the probability to obtain images without clouds coverage with a constant capturing.
ND05.	To have access to images of other complementary satellites by means of cooperation and exchange with other countries and agencies.
ND06.	To have a detailed coverage minimum of 250 m of terrain.

Step 3. Identify internal and external constraints

In this step, the internal and external constraints are going to be identified based on the preliminary Objectives and needs research likewise, data taken form reference [13] from the Earth Observation Magazine 2010,

The list shown below is for the top constraints based on the research form "*Programa de Investigación en Desarrollo Satelital y Aplicaciones en el Tema de Observación de la Tierra*" [13].

In addition, the information gathered on this project. Likewise, the left column for internal and right column for external constraints in regards to the Earth Observation for the Colombian Earth surface. See table 3.3 "Identifying internal and external constraints".

Table 3.3. Identifying internal and external constraints.
Source: Author

IDENTIFYING INTERNAL AND EXTERNAL CONSTRAINTS			
NºC.	**INTERNAL**	**NºC.**	**EXTERNAL**
CN01	Cost	**CN02**	Funding
CN03	Design life	**CN04**	Regulations- law
CN05	Infrastructure	**CN06**	Schedule
CN07	Orbit	**CN08**	Sponsoring
CN09	Autonomy	**CN10**	cloudiness
CN11	Materials Availability	**CN12**	Cartography
CN13	Experienced personnel (knowledge)	-	-
CN15	Payload quality	-	-
CN17	Software	-	-
CN19	Installations	-	-

Step 4. Translate customer/user needs

In this step, the customer/user needs are going to be translated into functional attributes and system characteristics. While there are several structured approaches to developing requirements form customer/user needs, the most commonly used tool is Quality Function Deployment or QFD [8].

As a summary, the QFD is used to connect customer needs or requirements to technical attributes or requirements; in this section, the "House of Quality" (see chapter 1, section 1.9.1) is going to be developed, see figure 3.3 "House of Quality, Customer/user needs and requirements".

Likewise, with the information gathered in this chapter about the requirements of the client/user, constraints, needs and functional attributes, the next steps are going to be reviewed in a "systems requirements review" (chapter 4) and shall complement this requirements set-up as for the accomplishment of the systemically systems requirements review.

House of Quality

Customer & user needs \ Functional attributes	Importance	Orbital Altitude (FA02)	Coverage (FA04)	Orbit nodal Position (FA05)	Resolution (FA05)	Data Processing (FA06)	Remote Sensing (FA01)
To increase the probability to obtain images without clouds coverage with a constant capturing **(ND04).**	3	9	3	9	9	3	9
To obtain right resolution images with costs reductions **(ND01).**	9	3	9	3	9	3	9
To have a detailed coverage minimum of 250 m of terrain **(ND06).**	9	9	9	9	9	3	9
To be able to count with periodic updated information **(ND02).**	3	3	3	3	3	9	9
To have access to images of other complementary satellites by means of cooperation and exchange with other countries and agencies **(ND05).**	3	9	3	3	3	3	3
To have autonomy for the images capturing in priority places for emergency cases or other matters **(ND03).**	3	3	3	3	3	3	9
	∑	36	30	30	36	24	48

Figure 3.3. House of Quality, Customer/user needs and requirements. Source: Author

As a result of the house of quality, the main functional attributes were found and categorized from the highest to the lowest relevance, summarized tin table 3.4 “Functional attributes”. This attributes shall be reviewed one by one in step 1, chapter 4.

Table 3.4. Functional attributes. Source: Author

FUNCTIONAL ATTRIBUTES			
NºC.	**Attribute**	**NºC.**	**Attribute**
FA01.	Remote Sensing		-
FA02.	Orbital Altitude	**FA03.**	Resolution
FA04.	Coverage	**FA05.**	Orbital parameters/Elements
FA06.	Data Processing		-

CHAPTER 4 – SYSTEMS REQUIREMENTS REVIEW (SRR)

This chapter is a continuation of chapter 3 as explained in chapter 3 figure 3.1, for setting up a requirements baseline and using as a reference the Systems engineering general requirements European Standard [16], the Space Mission analysis design [8] and the A-B-Cs Sun-Synchronous Orbit Mission design [18]. These references will also contribute with the steps for developing some calculous needed as for the technical specifications i.e. the orbital altitude, orbit nodal position and orbit parameters.

This chapter has the aim of developing the systems requirements as part of the Mission requirements baseline of this research and it shall be performed in a systemically review form as shown from the step 5 to 9.
Note: The System in this case is considered to be the whole satellite and the subsystems (power, remote sensing, structure and the others explained below) as the ones that compose the system (satellite).

- Every subsystem is going to be reviewed one by one in order to be explained as one (a system) having on mind the previous note.

Step 5. Functional requirements for systems

In this section, the Functional requirements for systems are going to be established and shall provide decomposition to elements in step 6 throughout a functional analysis. Using as a reference the top-level mission requirements from the Space Mission design sec. 1.4 [8] adjusted to this mission for the Colombian Earth Observation.

For the development of the functional requirements for systems, a relationship between systems, requirements and customer/user needs have to be established [16]. in first instance, the customer/user needs (as established in table 3.2, chapter 3) are going to be reviewed along with the systems "affected" ever since there is a need of acknowledging which systems may be affected in the moment of solving a customer/user need [8]. See table 4.1 "User/customer needs and systems affected relationship".

Afterwards, this relationship is going to be used as the spot to establish a functional requirements baseline. Hence, this information is going to be linked with the Functional requirements and becoming this the functional relationship of this research.

Table 4.1 User/customer needs and systems affected relationship, following to diagrams 4.3 and 4.4.
Source: Author

User/customer needs and systems affected relationship	
User/customer needs	**Subsystem affected**
To obtain right resolution images with costs reductions **(ND01)**	- Remote sensing Subsystem **(SBS01)** - Power Subsystem. **(SBS02)** - Structure and Mechanisms Subsystem. **(SBS03)**
To be able to count with periodic updated information. **(ND02)**	- Remote sensing Subsystem. **(SBS01)** - Dada handling Subsystem. **(SBS04)** - Communication Subsystem. **(SBS05)**
To have autonomy for the images capturing in priority places for emergency cases or other matters. **(ND03)**	-Telemetry, Communication and command Subsystem. **(SBS05)** - Altitude and Orbit Control Subsystem (AOCS). **(SBS06)** - Dada handling Subsystem. **(SBS04)** - Propulsion system. **(SBS07)**
To increase the probability to obtain images without clouds coverage with a constant capturing. **(ND04)**	- Dada handling Subsystem. **(SBS04)** - Remote sensing Subsystem. **(SBS01)**
To have access to images of other complementary satellites by means of cooperation and exchange with other countries and agencies. **(ND05)**	-Telemetry, Communication and command Subsystem. **(SBS05)** - Altitude and Orbit Control Subsystem (AOCS). **(SBS06)** - Remote sensing Subsystem. **(SBS01)**
To have a detailed coverage minimum of 250 m of terrain **(ND06)**	- Thermal subsystem. **(SBS07)** - Power subsystem. **(SBS08)** - Structure and Mechanisms Subsystem. **(SBS03)**

Right after having the relationship between user/customer needs and systems affected by them, the preliminary functional requirements are going to be expressed in relationship diagram, using the data of table 4.1 "User/customer needs and systems affected relationship". Likewise refer to diagrams 4.3 and 4.4 for relationship graphics illustration.

Hence, the Main Functional requirements that apply to the Earth Observation Mission type are studied and adjusted to the project, reference form the SMAD book [8]. The diagrams 4.1.1 to 4.1.7 are studied one by one as part of a systems and functional requirements illustration, being those seven diagrams a clearer relationship between needs, requirements and each system.

The Customer/User needs are the main input of the diagram, then the relation with the systems affected (second input) and finally the requirements that this research shall use as baseline to solve the needs.

This definition of the diagram 4.1.2 and table 4.1.7 are going to be used in step 6 and forward as the reference of the Satellite systems and functional requirements for the Colombian Earth Observation mission.

The remote sensing Subsystem: The remote sensing subsystem is represented in the diagram 4.1.1 "*Functional requirements for the Remote Sensing System*" and it stands for the remote sensing subsystem affected by the customer/user discussed in chapter 2. This diagram is divided into three types of blocks: Customer/user needs (such as the **ND01, ND02, ND04, ND05** and **ND06),** see diagram 4.1.1

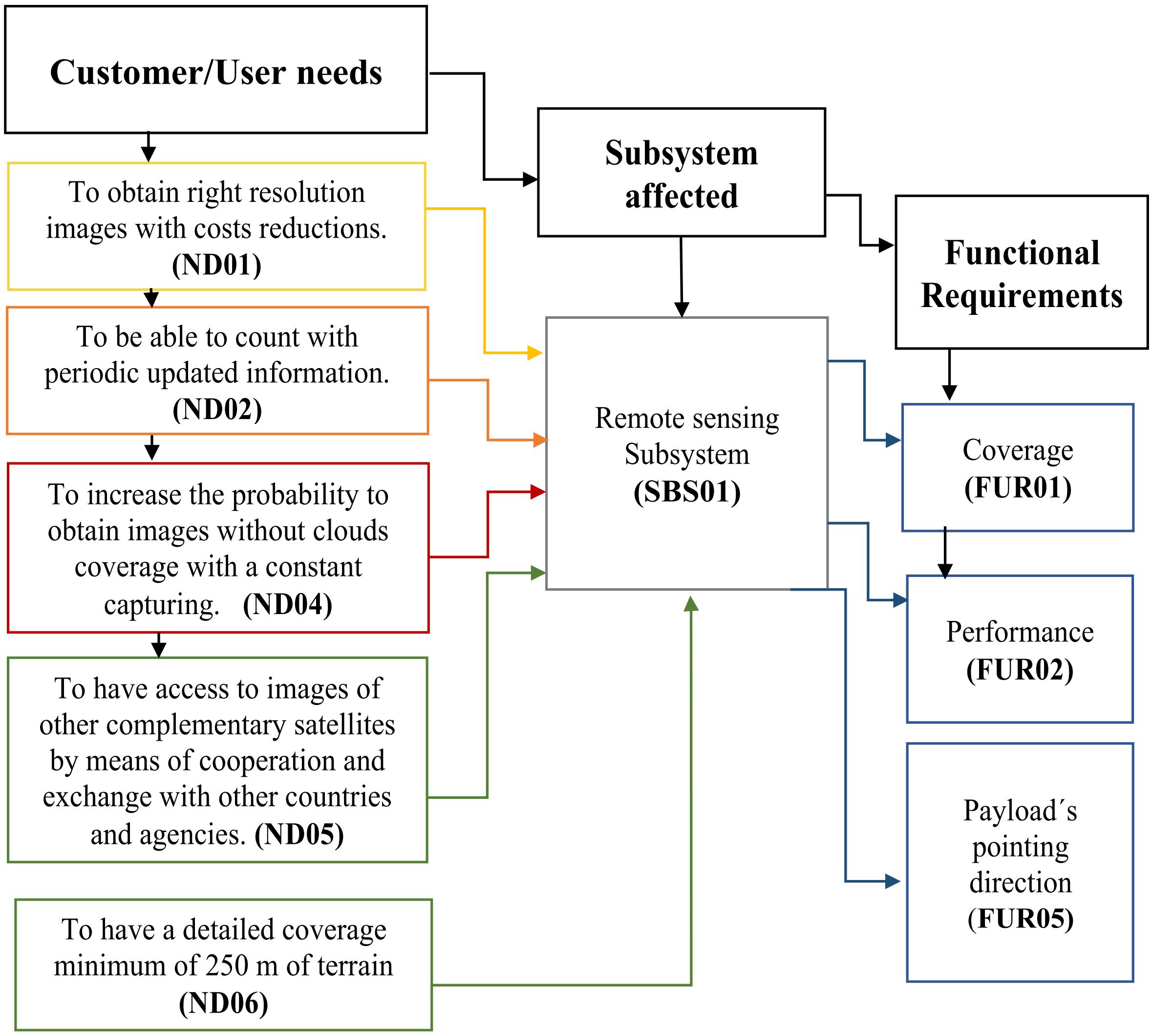

Diagram 4.1.1 Functional requirements for the Remote Sensing Subsystem, Customer/user needs and systems affected from table 4.1 and reference [13] and [31].

The Power Subsystem: The Power subsystem is represented in the diagram 4.1.2 "*Functional requirements for the power System*" and it stands for the power subsystem affected by the customer/user discussed in chapter 2. This diagram is divided into three types of blocks: Customer/user needs (such as the **ND01** and **ND06**), see diagram 4.1.2

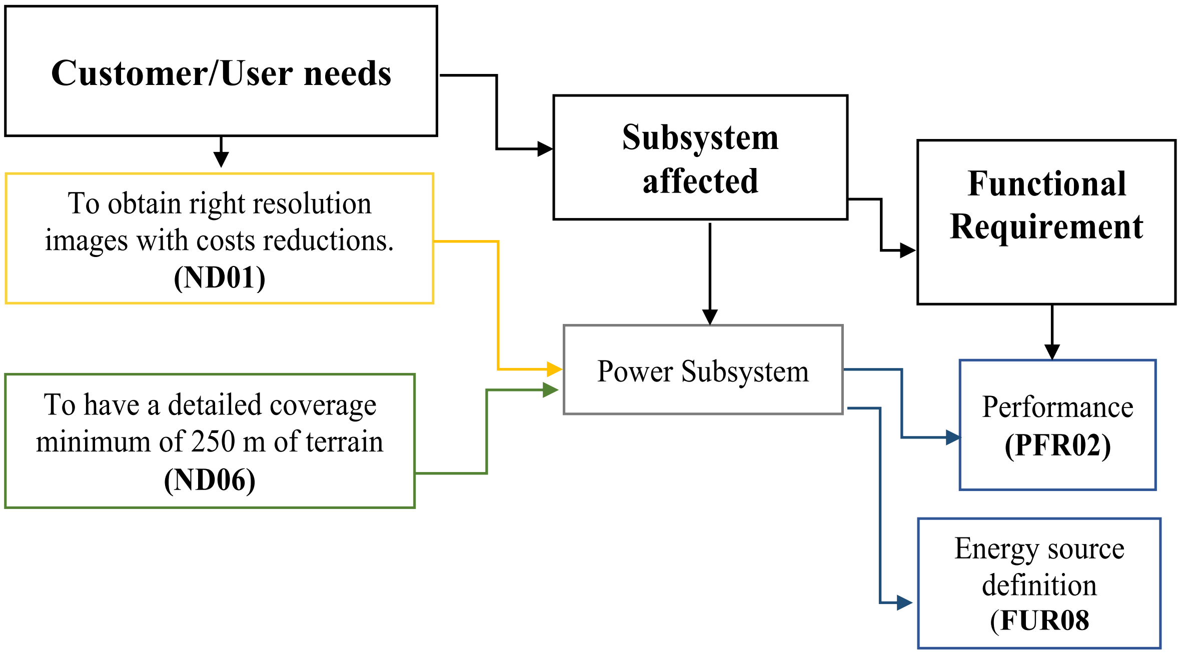

Diagram 4.1.2 Functional requirements for the Power Subsystem, Customer/user needs and systems affected from table 4.1 and reference [13] and [31].

The Structure and Mechanisms Subsystem: The Structure and Mechanisms Subsystem is represented in the diagram 4.1.3 "*Functional requirements for the structure and mechanisms Subsystem*" and it stands for the power subsystem affected by the customer/user discussed in chapter 2. This diagram is divided into three types of blocks: Customer/user needs (such as the **ND01**), see diagram 4.1.3

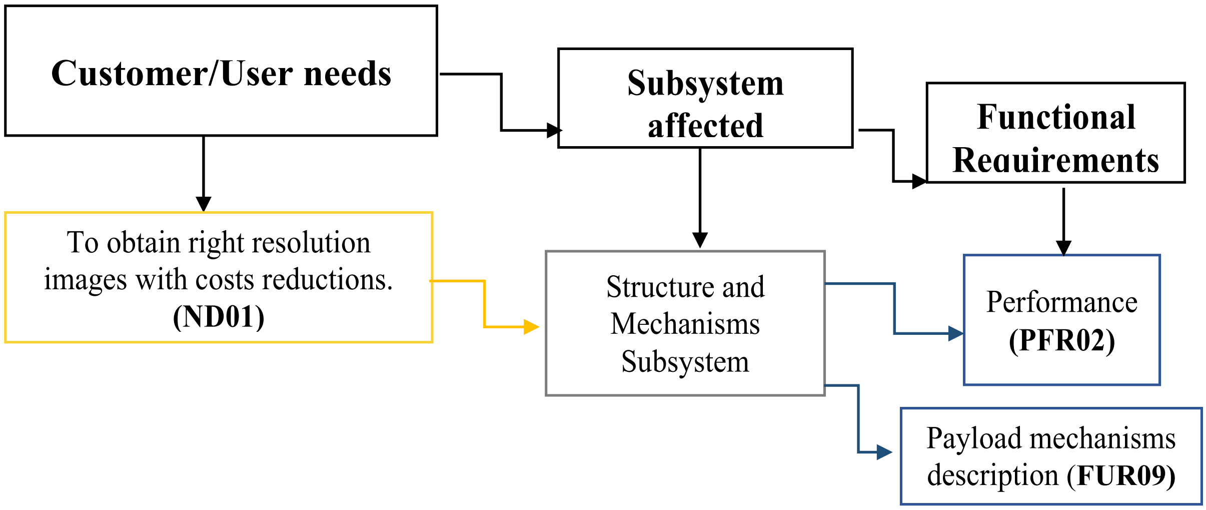

Diagram 4.1.3 Functional requirements for the structure and mechanisms Subsystem, Customer/user needs and systems affected from table 4.1 and reference [13] and [31].

The Data Handling Subsystem: The Data Handling Subsystem is represented in the diagram 4.1.4 "*Functional requirements for the Data Handling Subsystem*" and it stands for the power subsystem affected by the customer/user discussed in chapter 2. This diagram is divided into three types of blocks: Customer/user needs (such as the **ND02, ND03, ND04** and **ND05**) see diagram 4.1.4

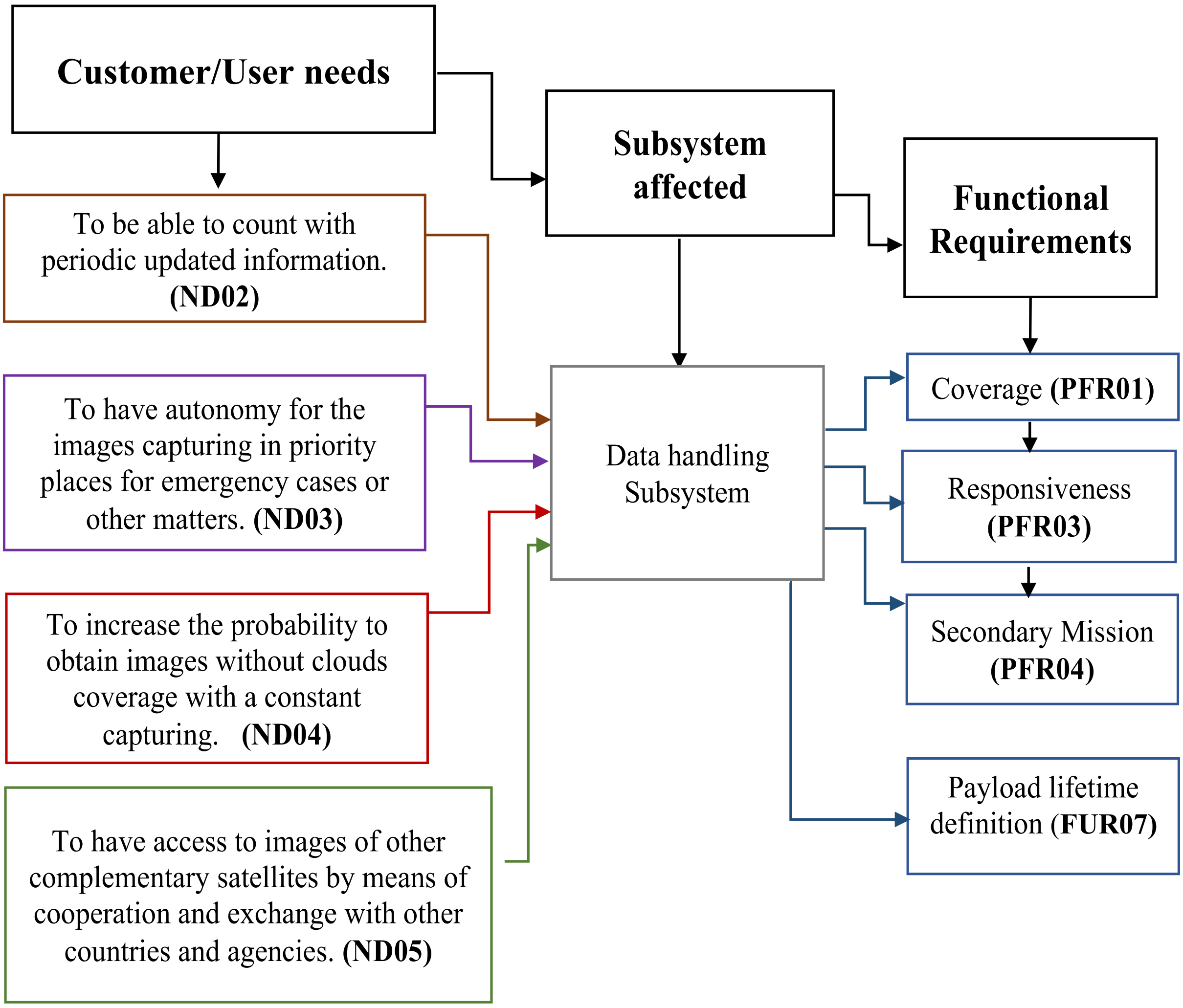

Diagram 4.1.4 Functional requirements for the Data Handling Subsystem, Customer/user needs and systems affected from table 4.1 and reference [13] and [31].

The Propulsion, thermal and AOCS Subsystems: The Propulsion, thermal and AOCS Subsystems are represented in the diagram 4.1.5 "*Functional requirements for* the *Propulsion, thermal and AOCS Subsystems*" and it stands for the power subsystem affected by the customer/user discussed in chapter 2. This diagram is divided into three types of blocks: Customer/user needs (such as the **ND03** and **ND04**) see diagram 4.1.5

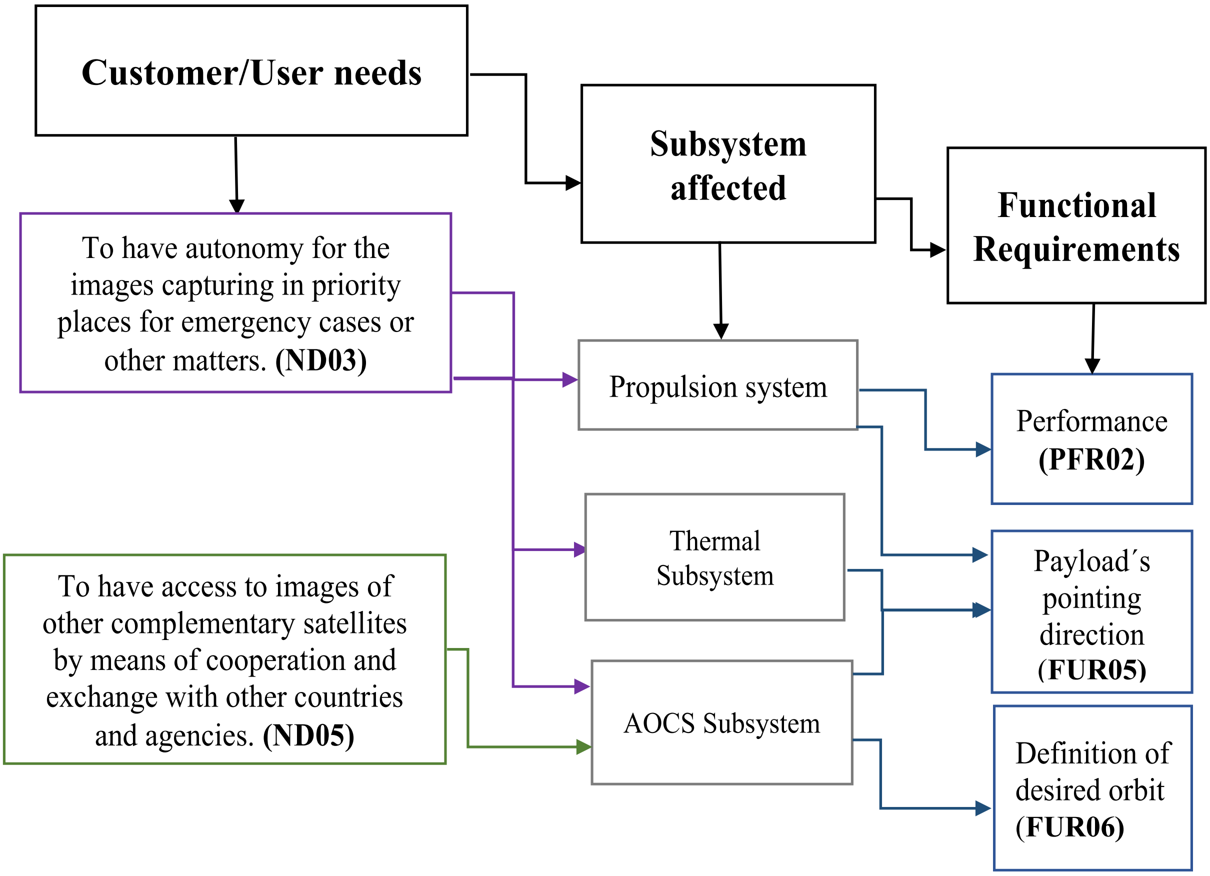

Diagram 4.1.5. Functional requirements for the Propulsion, thermal and AOCS Subsystems, Customer/user needs and systems affected from table 4.1 and reference [13].

<u>*The communications, telemetry and command subsystems:*</u> The communications, telemetry and command subsystems are represented in the diagram 4.1.4 "*Functional requirements for the communications, telemetry and command subsystems*" and it stands for the power subsystem affected by the customer/user discussed in chapter 2. This diagram is divided into three types of blocks: Customer/user needs (such as the **ND02, ND03, ND04** and **ND05**) see diagram 4.1.6.

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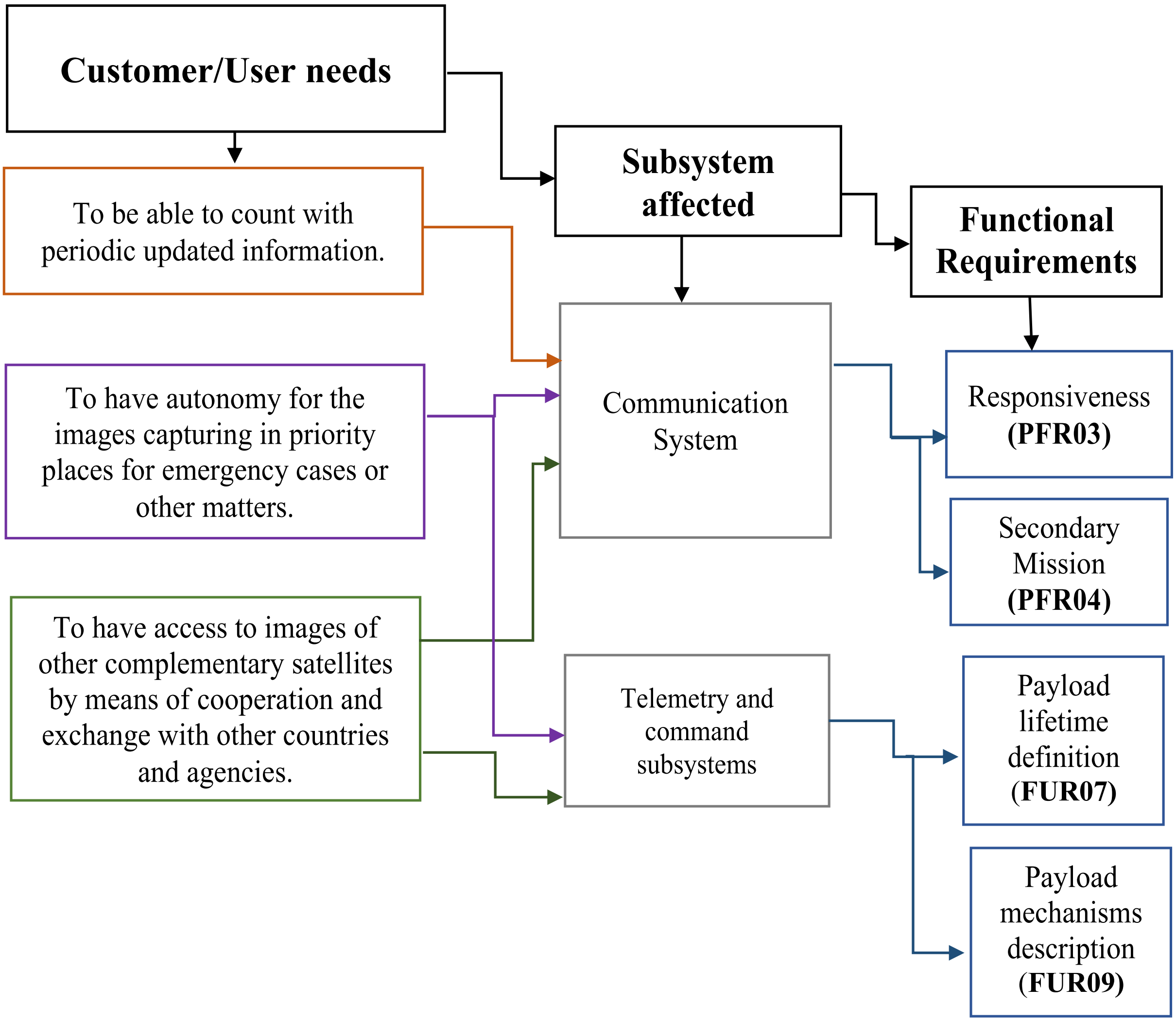

Diagram 4.1.6. Functional requirements for the communications, telemetry and command subsystems, Customer/user needs and systems affected from table 4.1 and reference [13].

As result of the diagrams 4.1.1 to 4.1.6 previously discussed, where it states the top requirements, these in a summary are:
The Performance, coverage, responsiveness and secondary mission and they are going to be used as the baseline for solving the user/costumer needs as the mission is developed, represented in the systems and subsystems as issued in the next steps of this chapter.

Step 6. Functional flow and representative

After defining the Customer/user needs (as it is shown in table 3.2), the functional attributes (as it is registered in table 3.4) and the functional requirements for systems (reference step 5), this enchained information should be expressed through a process of functional Analysis.

Functional analysis is the systematic process of identifying, describing, and relating the functions a system must perform in order to be successful afterwards, this functional analysis proceeds to lower levels of the system decomposition to define the system functional design and interfaces according to NASA systems engineering Handbook 1995 [17].

Likewise, in the Functional analysis there are different ways to address how this functions will be performed and the simplest way to express functions-or actions by or within each element of a system is by means of a functional flow block diagram [8]. In this step, each Subsystem previously discussed as stated in the table 4.1 is going to be represented in the functional diagram, see diagram 4.2.1 to 4.2.8. “Functional diagram for systems”.

<u>Diagram 4.2.1 Remote sensing Subsystem:</u> The functional flow of the Remote Sensing Subsystem is represented with the Diagram 4.2.1 using as reference the interfaces and functions from [19] and [42] along with the Spacecraft Systems Engineering book [32], this functional flow sets as the input: The Type of sensing and Orbital parameters definition. The input data works along with the elements **(ERS01-ERS05)** for becoming functions in the development of the remote sensing and finally setting outputs, which are The Systems monitoring and Data download as some types of outputs obtained throughout the functions performance.

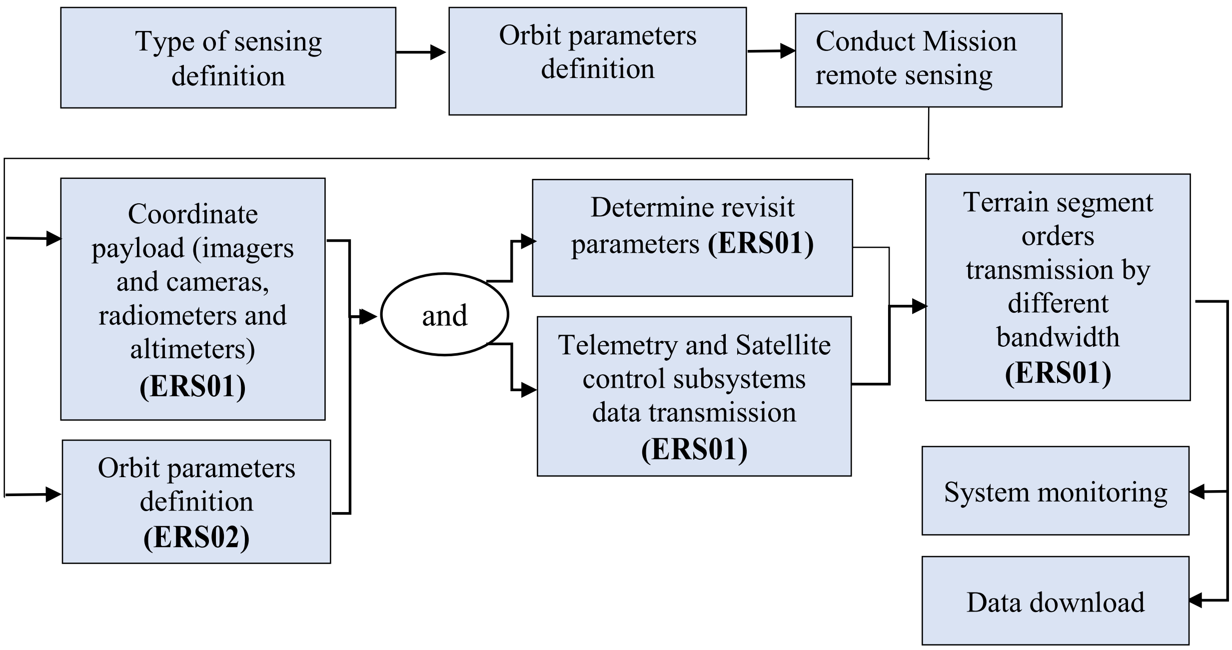

Diagram 4.2.1 Functional diagram for the Remote Sensing Subsystem.
Source: Author

Diagram 4.2.2 Power Subsystem: The functional flow of the Power Subsystem is represented with the Diagram 4.2.2 using as reference the interfaces and functions from [35] and [37] along with the Spacecraft Systems Engineering book [32], this functional flow sets as the input: The Power plant/battery source, Hardware and interfaces definition and Subsystems integration and test. The input data works along with the elements **(EPS01-EPS05);** using a check- up action on the **EPS04**, then becoming functions in the development of the power subsystem, and finally setting an output, which is: The development check-up throughout lifetime as one type of output obtained throughout the functions performance.

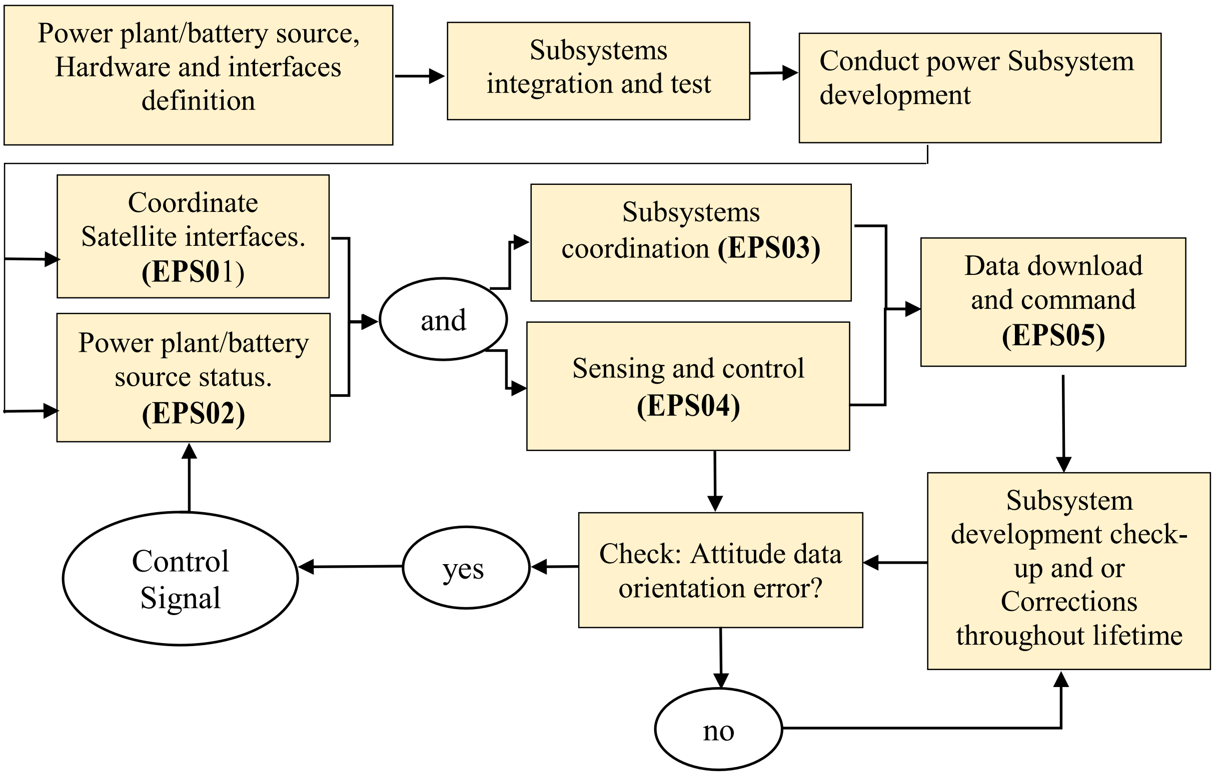

Diagram 4.2.2 Functional diagram for the Power Subsystem
Source: Author.

Diagram 4.2.3 Structure and mechanisms Subsystem: The functional flow of the structure and mechanisms Subsystem is represented with the Diagram 4.2.3 using as reference the interfaces and functions from [35] and [37] along with the Spacecraft Systems Engineering book [32], this functional flow sets as the input: The Dimensions, materials selection and design Systems integration and test.. The input data works along with the elements **(ESS01-ESS05);** using a check- up action on the **ESS04**, then becoming functions in the development of the structure and mechanisms and finally setting an output, which is the development check-up throughout lifetime and or Corrections throughout lifetime as one type of output obtained throughout the functions performance.

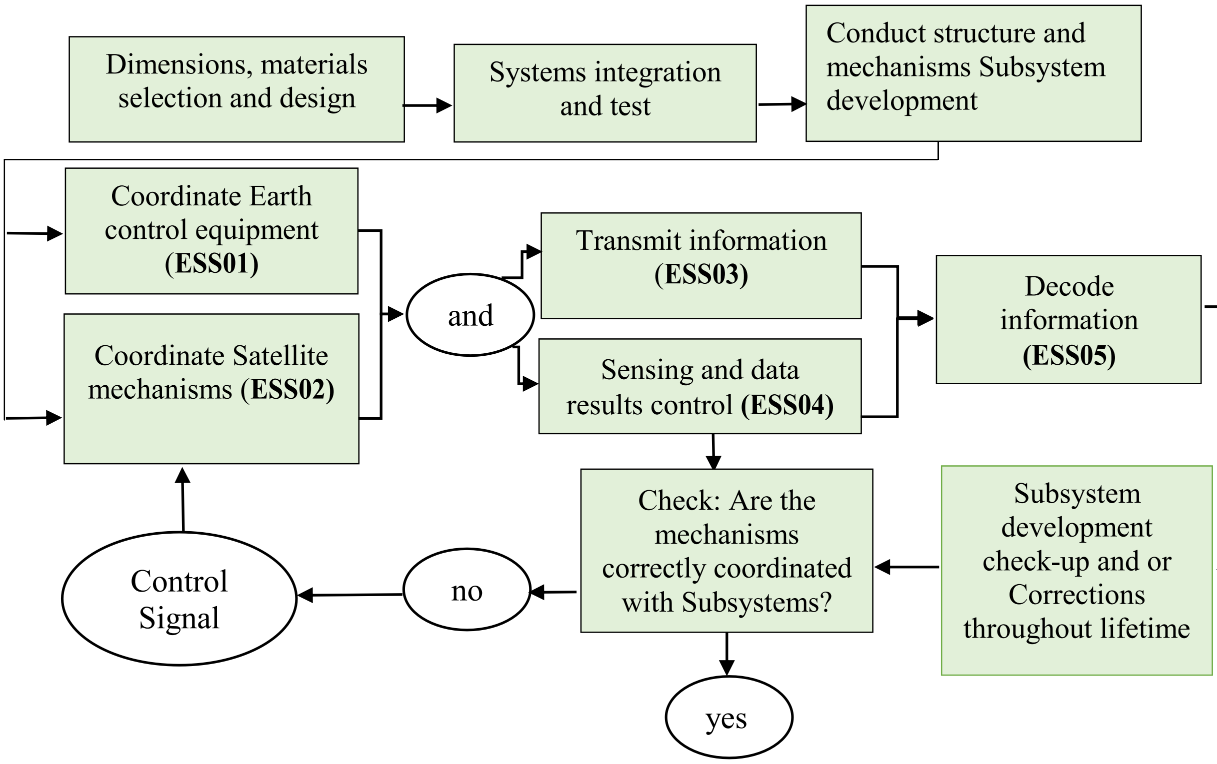

Diagram 4.2.3 Functional diagram for the structure and mechanisms Subsystem.
Source: Author

Diagram 4.2.4 Data Handling: The functional flow of the Data Handling Subsystem is represented with the Diagram 4.2.4 using as reference the interfaces and functions from [35] and [37] along with the Spacecraft Systems Engineering book [32], this functional flow sets as the input: The Computing techniques selection and design and Systems integration and test. The input data works along with the elements **(EDS01-EDS05)** for becoming functions in the development of the Data Handling and finally setting outputs, which are the Transfer information to bus data acquisition equipment and data computing information decoded as some types of outputs obtained throughout the functions performance.

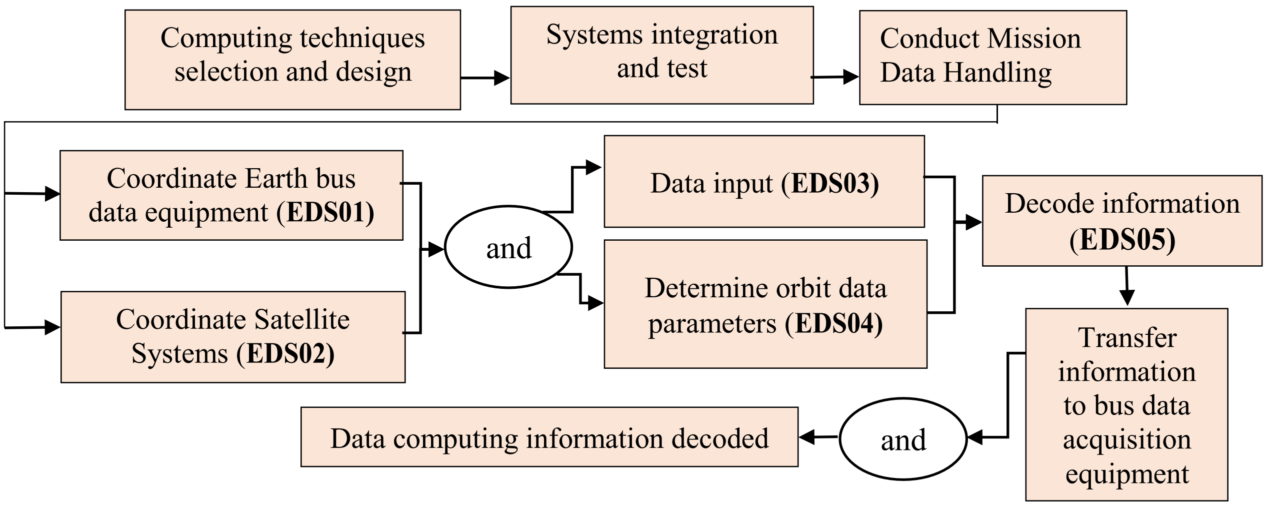

Diagram 4.2.4 Functional diagram for the Data Handling Subsystem system.
Source: Author

Diagram 4.2.5 Propulsion, thermal and AOCS Subsystems: The functional flow of the Propulsion, thermal and AOCS Subsystems is represented with the Diagram 4.2.5. Using as reference the interfaces and functions from [35] and [37] along with the Spacecraft Systems Engineering book [32], this functional flow sets as the input: The Orbital elements, physical and thermal interfaces definition next to the Systems integration and test. The input data works along with the elements **(EAS01-EAS04);** using a check- up action on the **EAS03** for becoming functions in the development of the Propulsion, thermal and AOCS Subsystems and finally setting an output, which is the development check-up throughout lifetime and or Corrections throughout lifetime as one type of output obtained throughout the functions performance.

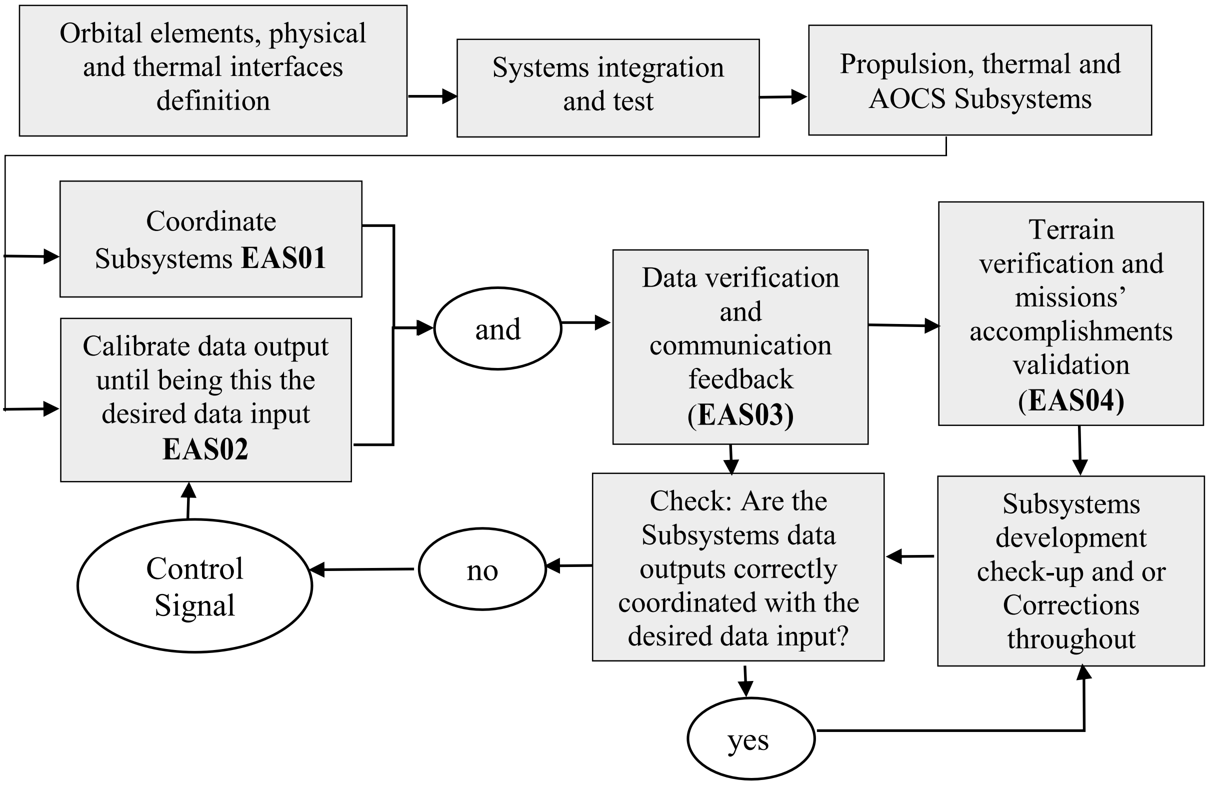

Diagram 4.2.5 Functional diagram for the Propulsion, thermal and AOCS Subsystems.
Source: Author

Diagram 4.2.6 Communications, telemetry and command subsystems: The functional flow of the Communications, telemetry and command subsystems is represented with the Diagram 4.2.6. Using as reference the interfaces and functions from [35] and [37] along with the Spacecraft Systems Engineering book [32], this functional flow sets as the input: The Payload selection and structure design next to the Systems integration and test. The input data works along with the elements **(ECS01-ECS05)** for becoming functions in the development of the Communications, telemetry and command hence, finally setting an output, which are: The Systems monitoring and Data download as some types of outputs obtained throughout the functions performance

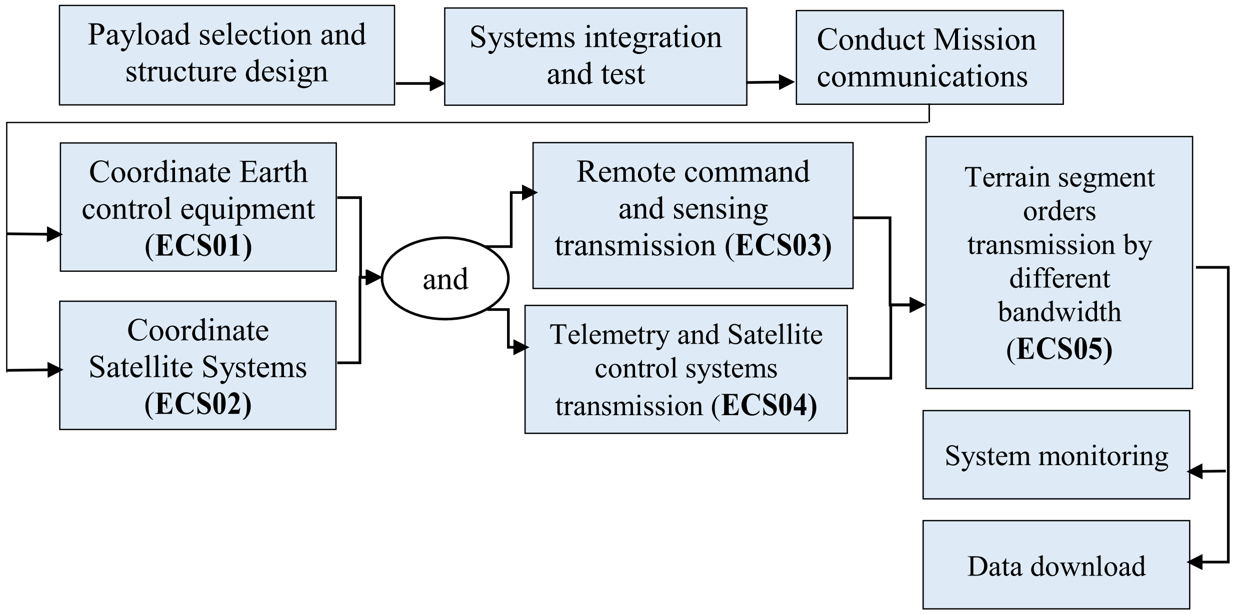

Diagram 4.2.6 Functional diagram for the communications, telemetry and command subsystems.

Source: Author

<u>Step 7. Translate functional attributes</u>

For this step, the functional attributes (as defined in step 4, chapter 4 of this document) are going to be translated into technical characteristics, which will become the requirements for the physical system.

The next sub-steps are based on the “Research program of Satellite development and applications in the Earth Observation matters” exposed on the Earth Observation Magazine of the CCE [13]. Likewise, the handbook for SS-O mission design [18].

7.1 Remote Sensing

The remote sensing (sub-step) is the most relevant functional attribute in this mission accomplishment as it is shown in step 4 and before any analysis of the Earth Observation technical characteristics; the remote sensing concept has to be understood.

Remote sensing is considered in the space science, any observation that a spacecraft makes without directly contacting the object in question. Imaging the Earth's surface, sounding the Earth's atmosphere, providing early warning of a ballistic missile launch, or observing the characteristic chemical spectra of distant galaxies are all remote sensing missions [8].

As explained in chapter 1, section 1.6 the remote sensing types are two "passive" and "active". The Active remote sensing is the one which instrument emits energy actively rather than collecting information about light energy from another source (the sun) [20] as it happens in the "passive". Refer to chapter 1, section 1.5 & 1.6 for further reference of remote sensing. For the qualities of the type of instrument, it has been decided that the passive method is the one used ever since this project is focused on the images that are produced from the reflection of light on the earth.

There are different types of imagery for the data sensing and according to the Earth Lab of the University Colorado [20], one of those is the multispectral imagery, which is produced by sensors that measure reflected energy within several specific sections (also called bands) of the electromagnetic spectrum. The electromagnetic spectrum is composed of a range of different wavelengths or "colors" of light energy. A spectral remote sensing instrument collects light energy within specific regions of the electromagnetic spectrum. Each region in the spectrum is referred to as a band [20].

The use of multispectral bands is a priority (as discussed in step 2, chapter 4) in the Colombian Earth Observation requirements and this is mainly because the radar data does not count with a massive appropriation nor a great number of operative applications in the country yet [13]. This specification gets to the conclusion of using multispectral bands for the remote sensing as in accordance to the technical specifications of the "Research program of Satellite development and applications in the Earth Observation matters" established in reference [13] and meets to the CCE (user) needs, this information is gathered in the table 4.2 "remote sensing- technical characteristic"

Table 4.2. Remote sensing- technical characteristic, as reference technical specification of the Research program of Satellite development and applications in the Earth Observation matters [13]

REMOTE SENSING- TECHNICAL CHARACTERISTIC		
FUNCTIONAL ATTRIBUTE	**TECHNICAL CHARACTERISTIC**	
Remote sensing **(FUA01)**	**Characteristic (TEC)**	**Specification**
	Multispectral Optical sensing **(TEC01)**	5 (five) bands (blue, green, red, near and panoramic infrared).

7.2 Orbital altitude

Selecting the Orbit altitude is going to be needed as for the customer/user requirements accomplishment, having into account that there are different orbits for the earth observation as exposed in chapter 1, section 1.10 and gathering the Customer/user needs.

The model assumed to be used in the Colombian Earth Observation according to the CCE is going to be a sun-synchronous orbit (SS-O) because of the different factors that affect the requirements of the customer/user such as the right imaging, data access, constant sun light, coverage and orbital altitude definition (see chapter 1, section 1.10. For SS-O definition and properties).
The main use of the SS-O stands for the capacity to maintain the revisit parameters and stable geographic coverage with time, which means, the right illumination conditions for the images taken and it also allows making the planning of the images capturing and the uniformly communications links with the satellite over the mission lifetime [13].
As stated by the SS-O mission design Handbook [18], where the SS-O is considered as one of the most commonly used forms of earth orbit for space science missions. The primary reason for the frequent utility of the SS-O is that it readily provides many desirable orbital characteristics, which satisfy key mission requirements. Customer/user needs and requirements (step 2.) such as the coverage, communications and revisit [18].

To establish the orbital altitude parameters, in this case the Wertz definition [19] is taken as a reference, where low earth orbits are defined within altitudes below 1000 km; when being higher altitudes than 1000 km, the Van Allen radiation belts come into play by exposing the satellite to greater amounts of trapped radiation [18]. Hence, in this project, the maximum altitude is going to be 1000 km.
Likewise, at very low altitudes around 200 km-500 km the satellite can be seriously affected by atmospheric drag [18], this is the reason by the lowest altitude range for this project is going to be 500 km, see table 4.3 “Satellite Altitude- technical characteristic”.

Table 4.3 Satellite Altitude- technical characteristic, as reference the step VII. Selecting Orbit Altitude from the SS-O mission design Handbook, reference [18] and [13].

<table>
<tr><th colspan="3">SATELLITE ALTITUDE-TECHNICAL CHARACTERISTIC</th></tr>
<tr><th>FUNCTIONAL ATTRIBUTE</th><th colspan="2">TECHNICAL CHARACTERISTIC</th></tr>
<tr><td rowspan="2">Orbital altitude (FUA02)</td><td>Characteristic (TEC)</td><td>Specification</td></tr>
<tr><td>Orbital Altitude range (TEC02)</td><td>- Highest altitude of 1000 km
- Lowest altitude of 500 km</td></tr>
</table>

7.3 Resolution

This functional attribute of resolution is an attribute that greatly affects the mission accomplishment when it comes to the achievement of the payload specifications for the earth imaging as needed for the security/defense, risk and environment management (as illustrated in step 2, figure 3.2 User/customer needs definition).

Resolution differs in the remote sensing systems at the detail level which allows capturing images and this can be considered as four different types of resolution: Spatial, spectral, radiometric and temporal [23]. In this project, two types of resolution are going to be considered as for the accomplishment of the user/customer needs, in accordance to their technical specifications. Established in the “Research program of Satellite development and applications in the Earth Observation matters” [13], from the Earth Observation Magazine of the CCE and in the step 2, chapter four of this document: these are the spatial and temporal resolution.

Spatial resolution: According to the NASA Earth Observatory ask scientist [24], space resolution refers to the detail at which a satellite sensor "sees" the Earth; or the size of its individual pixels (picture elements) in its viewing "footprint" on the Earth's surface. More precisely, spatial resolution is the area of a single data point on Earth's surface measured by a satellite; temporal resolution is also considered a measure of the smallest object that can be resolved by the sensor or the linear dimension on the ground represented by each pixel [25].

According to the “Research program of Satellite development and applications in the Earth Observation matters” [13] in regards to the Colombian Earth Observation resolution. Required spatial resolutions can be found in a range, from the sub-symmetric range in topics of transportation, infrastructure, risks and detailed cartography, to more regional scales (20 – 30 m) for the process follow up in wide areas of the Colombian territory such as the monitory of the Amazons.

Temporal resolution: Temporal resolution according to the Applied Remote Sensing Training Program from the NASA [26] refers to how frequently a satellite can provide observation of the same area on the earth and it mostly depends on swath width of the satellite – the larger the swath – the higher the temporal resolution. Likewise, as stated by the NASA Earth Observatory askscientist [24], this temporal resolution also called revisit, the frequency at which a satellite "sees" or “revisit” a given point on Earth. “Temporal" means, "pertaining to Earthly time.

In the technical specifications of the customer/client, it was found needed to have a space resolution in panchromatic and multispectral with a determined temporal resolution and it is represented in the table 4.4 “Resolution- technical characteristic”.

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Table 4.4 Resolution- technical characteristic, as reference technical specification of the Research program of Satellite development and applications in the Earth Observation matters [13]

RESOLUTION-TECHNICAL CHARACTERISTIC		
FUNCTIONAL ATTRIBUTE	**TECHNICAL CHARACTERISTIC**	
	Characteristic (TEC)	**Specification**
RESOLUTION **(FUA03)**	Spatial resolution **(TEC03)**	From 1.25 m to 2.5 m in panchromatic, 5 to 10 in multispectral. (Up to 20-30 m scale resolution).
	Temporal resolution **(TEC04)**	Revisit by about 15 days.

7.4 Coverage

The Satellite coverage according to the International Journal of Advanced Computer Science and Applications paper [27] is defined as a region of the Earth where the satellite is seen at a minimum predefined elevation angle. This attribute is linked to other parameters such as the Altitude, Orbit nodal position and resolution (revisit and spatial) and its efficiency is affected by any change on those parameters.

As stated by the "Research program of Satellite development and applications in the Earth Observation matters" [13] and the Geographic Institute *Agustín Codazzi* [14] the cartography development about coverage and usage of the ground by means of the resolution systems is a common related issue of all sectors (sectors/areas defined in figure 3.2. "Areas of technologies application for the Earth Observation". Chapter 2). This allowed noticing the need to get to the scales shown in table 4.5 or even to some more detailed ones for the accomplishment of the functions and projects by regional and local scales.

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Table 4.5 Satellite coverage- technical characteristic, as reference technical specification of the Research program of Satellite development and applications in the Earth Observation matters [13]

SATELLITE COVERAGE-TECHNICAL CHARACTERISTIC		
FUNCTIONAL ATTRIBUTE	**TECHNICAL CHARACTERISTIC**	
Coverage **(FUA04)**	**Characteristic (TEC)**	**Specification**
	Minimum scale **(TEC05)**	250 m of terrain (scale 1:25.000 ref. [14])

7.5 Orbital parameters/Elements

In the systems engineering and orbit mission design, the orbital parameters have to be established for further mission analysis/ calculous and simulation (orbital parameters design and simulation preview established in chapter 5, section 1.12 of the mission design- simulation). Likewise, as explained in step 7.1. The SS-O is the orbit required to be used in the Colombian Earth Observation mission design. Therefore, the Orbital characteristics of a SS-O shall be reviewed in this step taking the reference from SS-O mission design Handbook [18] and the FAA Handbook for "Describing Orbits", Classic Orbital Elements (COEs) [27], along with the different parameters and they are shown in table 4.5.

The table 4.5 specification section uses the FAA Handbook for "Describing Orbits", Classic Orbital Elements (COEs) [27] (see chapter 1, section 1.12 "framework" for COEs reference). As a summary, this book gives the necessary steps or "checklist" for selecting the Orbital size, shape, orientation and spacecraft location and it will be calculated/ checked in chapter 5 when introducing the data and information gathered during the process of establishing the requirements baseline (chapter 4 and 5).

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Table 4.6 Orbital Parameters/Elements- technical characteristic, as reference the step VII. Selecting Orbit Altitude from the SS-O mission design Handbook, reference [18] and the FAA Handbook for "Describing Orbits", Classic Orbital Elements (COEs) [27].

ORBITAL PARAMETERS-TECHNICAL CHARACTERISTIC		
FUNCTIONAL ATTRIBUTE	**TECHNICAL CHARACTERISTIC**	
Orbital parameters/Elements **(FUA05)**	**Characteristic (TEC)**	**Specification**
	Technical characteristic Orbital parameters/Elements	Orbital size which uses the semimajor axis, a **(TEC06)**
		Orbital shape that is defined by eccentricity, e **(TEC08)**
		Orientation of the orbital plane in space that uses: - inclination, I **(TEC09)** - right ascension of the ascending node, Ω
		Orientation of the orbit within the plane which is defined by argument of perigee, ω **(TEC10)**
		Spacecraft's location in the orbit that is represented by true anomaly, ν **(TEC11)**

7.6 Data Processing

Data processing is the functional attribute that works along with different systems functions likewise, it allows assembling/ gathering information between one system to another such the data processing (connection) between the structural and electrical system or the computing system and control system. This data processing allows accessing to the control and functioning of the systems by giving, receiving and processing the information required.

In the same case, according to the SMAD [8], mission data processing must receive, store, and process the mission data, sort it by user or by required media, and send it to the user, which allows accessing to the information and data required for the mission accomplishment.

Additionally, according to the "Research program of Satellite development and applications in the Earth Observation matters" [13]. In the research stated in step 2 (customer and user needs, figure 3.2 "Areas of technologies application for the Earth Observation").

In the diagnosis, 36 areas were defined as main priorities for the remote sensing for the Colombian Earth Observation and some particular needs were realized in regards to the data coming from remote sensing (see table 3.2, for customer/user needs, chapter 3). Likewise, for the needs of data updating, it is a priority to count with constant updated information, which allows the periodic monitoring of the earth coverage statute. For the specific topic of disasters prevention and attention, it is required to acquire immediately images when occurring an eventuality. The identified requirements point out the convenience of having an own system for the Earth observation to attend many needs in the country in regards to the data coming from the remote sensing [13].

Table 4.7 Data Processing- technical characteristic, as reference technical specification of the Research program of Satellite development and applications in the Earth Observation matters [13]

DATA PROCESSING-TECHNICAL CHARACTERISTIC		
FUNCTIONAL ATTRIBUTE	**TECHNICAL CHARACTERISTIC**	
	Characteristic (TEC)	**Specification**
Data Processing **(FUA06)**	Sensing data **(TEC07)**	To have autonomy to be able to take images in places of priority
		To allow access to other satellite images

<u>Step 8. Quantifiable requirement</u>

In this step, quantifiable requirements are going to be established ever since there is a need of defining a more specific requirements baseline (measurements of what, where, when or how). These quantifiable requirements are defined by is using the previous requirements from the steps above (step 1 to step 7) as the baseline and quantitative deployment.

Likewise, in order to establish a quantifiable requirement baseline and taking the concept of Quantifiable requirements of the One Step Testing page, reference [28], where it states the need of defining under which circumstances the system may fail to meet the requirement and after defining them, the quality measure can be set thence, it becomes a quantifiable requirement.
In the table 4.7.1 "Requirements Baseline-Quantifiable requirements", this deployment is represented with the following characteristics: the first column (1) is for the step from which the requirement shall be taken (Functional requirements **(FUR)** or technical characteristic for requirements **(TEC)** of the functional Attributes (FA)) is taken. The second column (2) is for the requirement from the steps 1 to 7, the third (3) is for the type of requirement, the fourth (4) column is the "quality" measure and the fifth column (5) goes for the quantifiable requirements. See table 4.7.1.

Table 4.7.1 Requirements Baseline-Quantifiable requirements, requirements baseline from all steps above and quantifiable guidelines.
Source: Author

REQUIREMENTS BASELINE-QUANTIFIABLE REQUIREMENTS				
1. Step	**Functional/Technical requirements**	**3. Type of applicable requirement**	**4. Quality measure**	**5. Quantifiable requirement**
5&7.4	Coverage **(FUR01)**	Functional and Physical (technical requirement)	Minimum scale of 250 m of terrain (scale 1:25.000 ref. [14])	To allow a coverage of a minimum scale of 250 m of terrain (scale 1:25.000) as for the Colombian Earth surface **(QFUR01)**
5&7.6	Responsiveness **(FUR03)** & Data sensing **(TEC07)**	Functional and Physical (technical requirement)	Send registered mission data within 15 min to up to 50 users*	To Send registered mission data within 15 min to up to 50 users* **(QF-T01)**
5&9	Payload´s pointing direction **(FUR05)**	Functional	Correct direction (Colombian Earth surface)	The payload must be pointed in the correct direction (Colombian Earth surface) 04 ° 00 N, 72 ° 00 w **(QFUR04)**
5&9	Payload lifetime definition **(FUR07)**	Functional	Lifetime of 10 years	The payload must be operable the whole mission lifetime of 10 years. **(QFUR06)**
5&9	Operation availability **(FUR08)**	Functional	Customer desired availability time	The payload must be operable and be reliable over the customer desired availability time (minimum of every 30 minutes). **(QFUR08)**
5&9	Definition of time communication (**FUR10)**	Functional	Time of 15 minutes	The data from the payload must be communicated to the ground every 15 minutes. **(QFUR10)**
7.1	Multispectral Optical sensing **(TEC01)**	Physical (technical characteristic)	5 bands (blue, green, red, near and panoramic infrared).	To count with a multispectral optical sensing of 5 bands (blue, green, red, near and panoramic infrared) **(QTR01)**

REQUIREMENTS BASELINE-QUANTIFIABLE REQUIREMENTS				
1. Step	**Functional/Technical requirements**	**3. Type of applicable requirement**	**4. Quality measure**	**5. Quantifiable requirement**
7.2	Orbital altitude range **(TEC02)**	Physical (technical requirement)	Highest altitude of 1000 km and lowest altitude of 500 km	To use an orbit with an altitude between the ranges of 500 km and 1000 km **(QTR02)**
5 &.3	Performance **(FUR02)** &Temporal resolution **(TEC04)**	Functional and Physical (technical requirement)	1.25 m to 2.5 m in panchromatic, 5 to 10 in multispectral and a scale resolution up to 20-30 m	To use a temporal resolution of 1.25 m to 2.5 m in panchromatic and 5 to 10 in multispectral and a scale resolution up to 20-30 m **(QF-T02)**
7.3	Spatial resolution **(TEC03)**	Physical (technical requirement)	Revisit by about 15 days.	To use a spatial resolution that allows a revisit by about 15 days. **(QTR03)**
7.6	Data sensing **(TEC07)**	Physical (technical requirement)	Autonomy to take images in places of priority of at least 2 areas of application (risk, regional, security & defense or environmental management)**	To have autonomy to take images in places of priority of at least 2 areas of application of risk, regional, security & defense or environmental management **(QTR09)**

* FireSat reference, LEO Satellite for fires detection, selection of quantity based on the objectives of the FireSat Mission and this Mission (Colombian Earth Observation)
** Areas of application for the Earth Observation, areas of priority in the remote sensing and Earth Observation.

1. Step from which the requirement is taken.
2. Requirement from the steps 1 to 7.
3. Type of requirement () Functional or Physical (technical characteristic).
4. Quality measure.
5. Quantifiable requirement

Step 9. Block diagrams relationships - systems level

In this final step for the system level, through the use of block diagrams, interfaces and hardware/software/data relationships are going to be defined using the reference form the EUROCKOT Launch systems – "Chapter 4 Spacecraft Interfaces" [30] and the SMAD book [8]. The interfaces are based on the systems already set in step 5 (Remote sensing, Communication, Propulsion, Computing, Control, Power and Structural system) see diagram 4.3 "Systems interfaces and hardware/software/data relationships". this definition shall allow viewing the relationship of the systems for the mission satellite and the final part of this step is establishing the main subsystems.

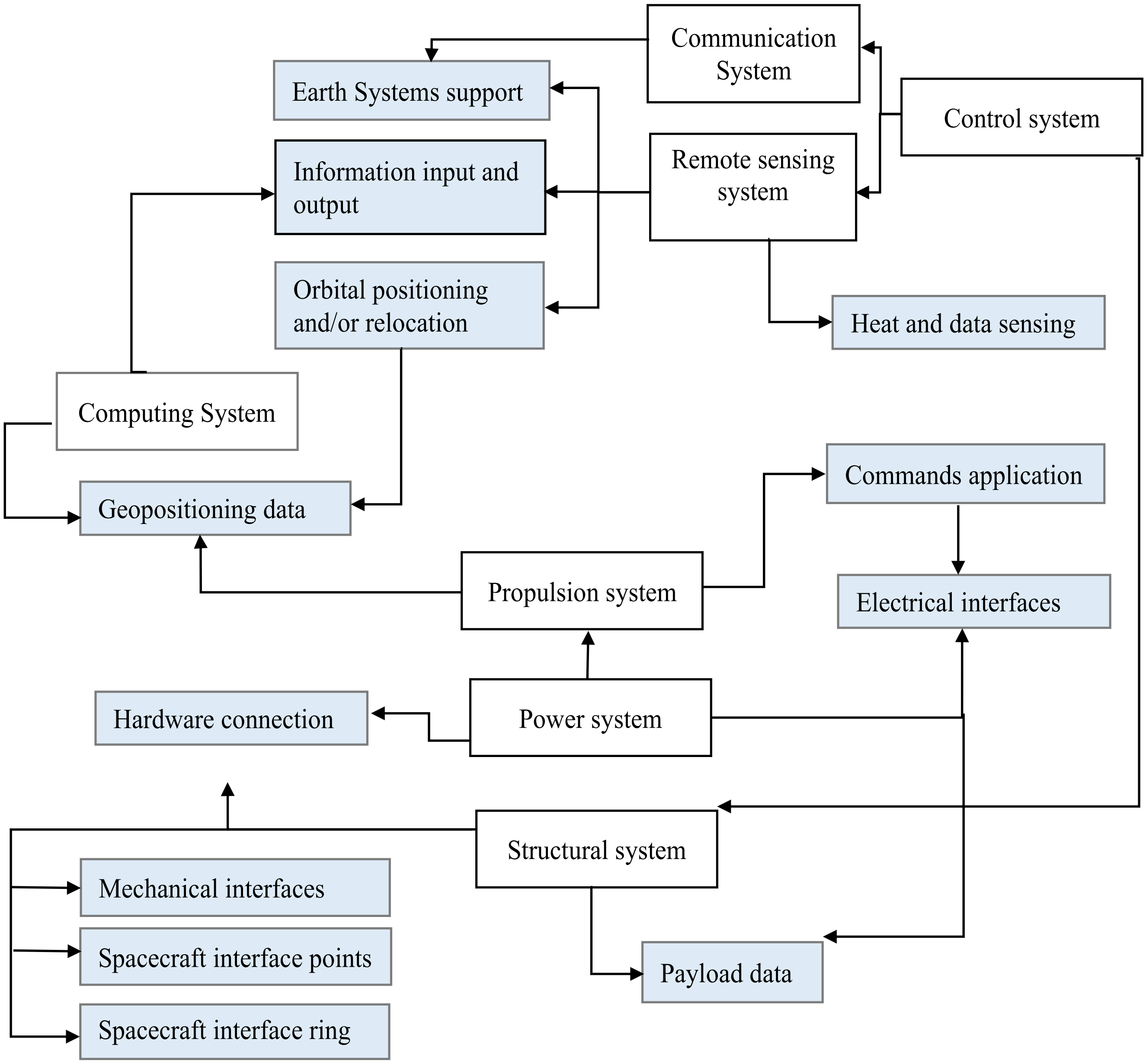

Diagram 4.3 Systems interfaces and hardware/software/data relationships.
Source: Author

The main subsystems are taken into account using the reference from the SMAD book, section 10.3 [8] and the Spacecraft Systems Engineering [31] and they are in a diagram relationship with the respective Functional requirement as taken from reference [31] section 1.2. See diagram 4.4 "**Satellite Subsystems & functional requirements,**"

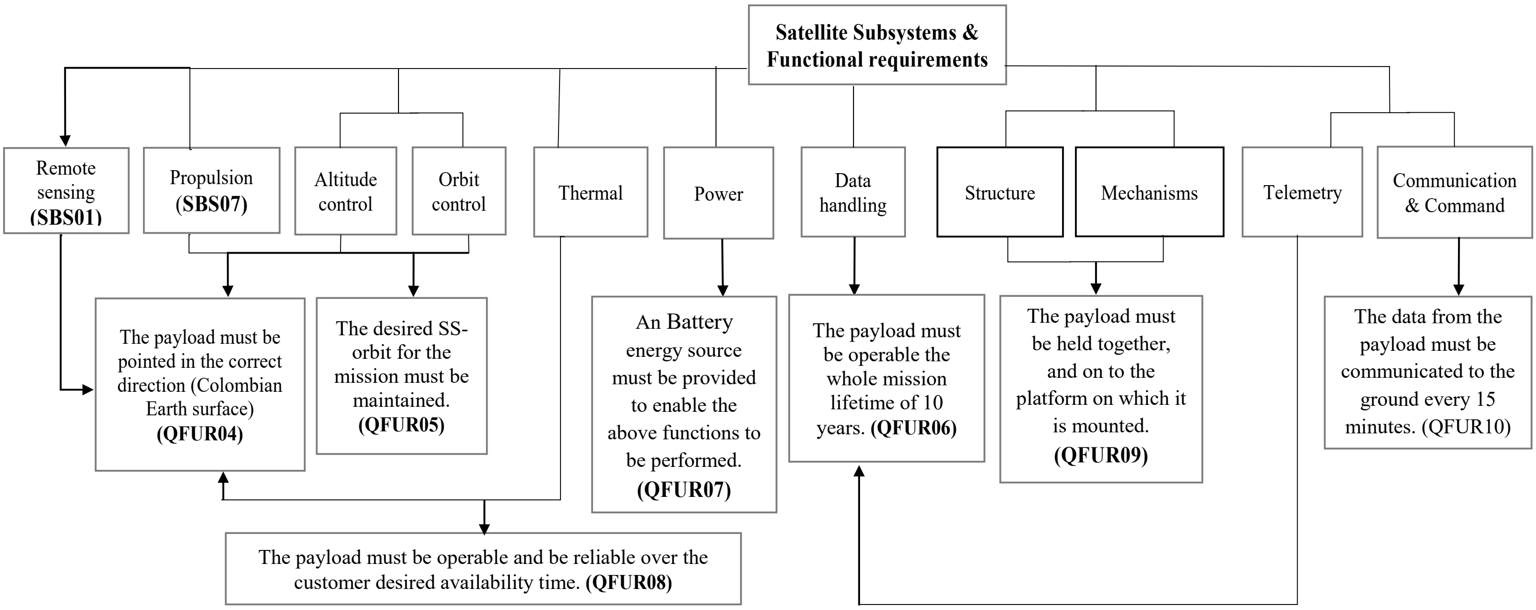

***Diagram 4.4 Satellite Subsystems & functional requirements*,** requirements adjusted to the mission based on the Spacecraft Systems Engineering [31].

REQUIREMENTS TABLE SUMAMRY

The next table is the summary of the Requirements collected in the Table 4.7.1 (using the preliminary functional and operational requirements (from chapter 2) along with the functional, physical and the technical characteristic in a quantifiable requirement (from chapter 5) and the diagram 4.4 (the Functional requirements collected from the Spacecraft Systems Engineering [31]. See table 4.8. “Requirements table summary”.

Table 4.8 Requirements table summary. Source: Author

REQUIREMENTS TABLE SUMAMRY		
NºC.	**TYPE OF REQUIREMENT**	**REQUIRMENET**
PFR01	Preliminary Functional requirement	Performance affected by the Payload, orbit, prototype, design, structure
PFR02	Preliminary Functional requirement	High quality images acquisition affected by the Payload selection and its design location
PFR03	Preliminary Functional requirement	Field of view affected by the commands definition, sensing system, computing, proper data set-up, payload
PFR04	Preliminary Functional requirement	Responsiveness affected by the computer processing, Software, sensors
PFR05-POR05	Preliminary Functional & Operational requirement	Survivability affected by the orbit, propulsion, and source of electrical power
POR01	Preliminary Operational requirement	Data managing, collecting and transfer affected by the computer, communications and sensors
POR02	Preliminary Operational requirement	Duration of materials, payload, orbital satellite continuity and Space debris
POR03	Preliminary Operational requirement	Command and controlling affected by the Earth receiving data architecture and Payload quality

REQUIREMENTS TABLE SUMAMRY		
NºC.	**TYPE OF REQUIREMENT**	**REQUIRMENET**
POR04	Preliminary Operational requirement	Satellite availability affected by the Materials endurance and life limits
QFUR01	Functional and Physical (technical requirement)	To allow a coverage of a minimum scale of 250 m of terrain (scale 1:25.000) as for the Colombian Earth surface
QF-T01	Functional and Physical (technical requirement)	To Send registered mission data within 15 min to up to 50 users.
FUR04	Functional requirement	To be able to connect to at least another satellite data.
QFUR04	Quantifiable-Functional requirement	The payload must be pointed in the correct direction (Colombian Surface) 04 ° 00 N, 72 ° 00 w.
FUR06	Functional requirement	The desired orbit for the mission must be maintained.
QFUR06	Quantifiable-Functional requirement	The payload must operate the whole mission lifetime of 10 years.
FUR08	Functional requirement	An energy source must be provided to enable the above functions to be performed.
QFUR08	Quantifiable-Functional requirement	The payload must be operable at customer desired availability time (minimum of every 30 minutes).
FUR09	Functional requirement	The payload must be held together, and on to the platform on which it is mounted.

REQUIREMENTS TABLE SUMAMRY		
NºC.	**TYPE OF REQUIREMENT**	**REQUIRMENET**
QFUR10	Quantifiable-Functional requirement	The data from the payload must be communicated to the ground.
QTR01	Quantifiable-Physical (technical characteristic)	To count with a multispectral optical sensing of 5 bands (blue, green, red, near and panoramic infrared).
QTR02	Quantifiable-Physical (technical requirement)	To use an orbit with an altitude between the ranges of 500 km and 1000 km.
QF-T02	Quantifiable-Functional and Physical (technical requirement)	To use a temporal resolution of 1.25 m to 2.5 m in panchromatic and 5 to 10 in multispectral and a scale resolution up to 20-30 m.
QTR03	Quantifiable-Physical (technical requirement)	To use a spatial resolution that allows a revisit by about 15 days.
QTR04	Quantifiable-Physical (technical requirement)-(simulation)	To work with an orbital size that uses the semimajor axis, a **(TEC06)**
QTR05	Quantifiable-Functional Requirement	To use an orbital shape that is defined by eccentricity, e **(TEC08)**
QTR06	Quantifiable-Functional Requirement	To work with an orientation of the orbital plane in space that uses an inclination (i) and right ascension of the ascending node, **Ω** **(TEC09)**
QTR07	Quantifiable-Functional Requirement	To use an orientation of the orbit within the plane which is defined by argument of perigee, ω **(TEC10)**
QTR08	Quantifiable-Functional Requirement	To define the spacecraft's location in the orbit that is represented by true anomaly, ν **(TEC11)**
QTR09	Quantifiable-Physical (technical requirement)	To have autonomy to take images in places of priority of at least 2 areas of application of risk, regional, security & defense or environmental management.

CHAPTER 5 – MISSION DESIGN “PARAMETERS DEFINITION, ANALYSIS OF RESULTS AND SIMULATION”

As stated from the beginning (chapter 1 and 2) of this project, this is a conceptual design of an Earth Observation Satellite with the limitations of Phase 0 and A (Conceptual phases) as in accordance to the Selected Standard ECSS-E-ST-10C [16] and the SMAD book [8] Chapter 1 to 4. These phases include the Mission Definition Review (MDR) in chapter 2, the Preliminary Requirements Review (PRR) in chapter 3 and the Systems Requirements Review (SRR) in chapter 4.

The conceptual phases are the Scope of this project; however, the purpose of this chapter is gathering the information of a Satellite simulation with the parameters for the Colombian Earth Observation. This is made as a plus for the Project understanding of a practical way in compliance with the chapter 2.8 and a possible baseline to continue with the Phase B “Preliminary definition” as in accordance with the Standard ECSS-E-ST-10C [16] for future projects development.

This chapter is going to be issued in two parts, one for the Mission parameters- Analysis and for Simulation (simulation used in a STK program, see chapter 1. Sec. 1.13 For program conceptual reference). For this project, the orbit parameters for a SS-O is going to be analyzed with the parameters determined in the Kepler’s equation (stated reference 18), see table 5.1. Using the comparison of an orbit with integer number of revolutions per day of 14 and 15 and the revolutions resulting from an equatorial altitude of 700 km.

Along with the comparison discussed above, there is going to be an analysis of the simulation and data obtained. This is performed in order to find simulate possible data for the Colombian Earth observation as addition and better graphic-analytical understanding of the Conceptual project.

See section 4.1 for the “Parameters Definition” and the section 4.2 for the “Analysis of Results” which uses the data of section 4.1 as for the Whole STK modeling process, afterwards, the section 4.3 stands for the Table of data obtained from the program and its analysis.

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5.1. PARAMETERS DEFINITION

As it was defined in chapter 2.8, table 2.7 “Performance Parameters for SatCo1-Mission utility”. There are various parameters to be analyzed and simulated (when applies) in order to better understand the mission accomplishment, in this case these parameters are the “Performance parameters” and they are going to be reviewed throughout this section of the chapter 5 and shall be the input data for the STK modelling and simulation section. These parameters are exposed in the points 1 to 5 below.

1. **Minimum coverage- Scale**
   The minimum coverage is the minimum percentage of earth’s surface to be accessible for observation [18] and it has already been given as a requirement from the User/customer in chapter:

   250 m of terrain or scale of 1:25.000, (see chapter 5 step 7.4)

   This will be represented in the STK simulation represented with the traceable orbit characteristic as the Orbit inclination and altitude. See Figure 5.1. “Orbit inclination and altitude” Altitude of 893.796 Km selected from the table 5.1 as for the usage of the Kepler’s equation and Right ascending node (RAAN) of 303.811 º

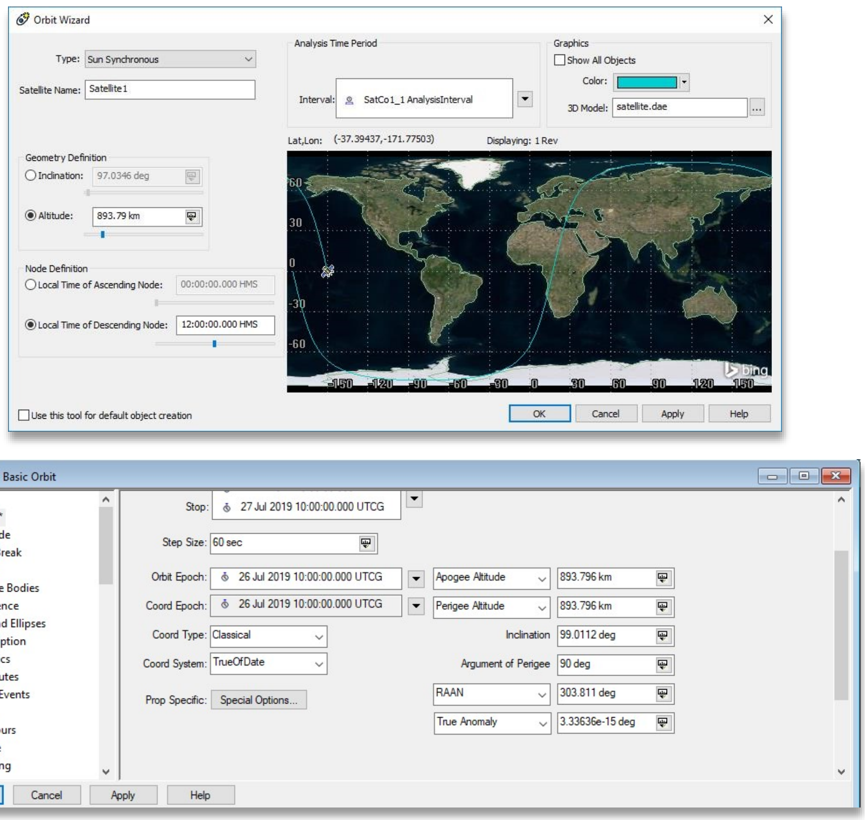


Figure 5.1 Orbit inclination and altitude, SS-O selection and data input in STK program for the Satellite simulation – Orbit data.
Source: Author

2. Mean time between observations

For the mean (solar) time between observation or "Reckoning Time" in a SS-O mission design, it is needed to understand that the Mean solar time is based on the length of a mean or average solar day, which is 24 hours long. It moves at a constant speed [38]. Likewise, there is also a way to represent the Mean solar time and it is by using the equation of Time, since the parameters for the earth's orbit are known quite well and considering that the obliquity of the ecliptic is also known well, it is possible to compute the Equation of Time as a function of calendar day [18].

Based on the SS-O Handbook [18], "Reckoning Time" is the rate at which the Earth rotates in a SS-O with respect to the vernal equinox and it is given by the interval where the earth rotates by 365.242199 revs with respect to the mean sun. However, one more time with respect to the vernal equinox, as a result, the period of time, in which it takes the earth to rotate once with respect to the vernal equinox (equation taken from reference 18) is given by:

$$\tau = 86400 * \left(\frac{365.242\,199}{1 + \ 365.242199}\right) = 816164.09\ s \qquad E1.\ (1)$$

$$\boldsymbol{\tau = 816164.09\ s}$$

The Mean time is determined by the Period and will be shown in the next point (three- "Orbital parameters") along with its graphic simulation, see image 5.2.

3. Orbital parameters/Elements

The orbital parameters are the guidelines of the mission data input for the orbit simulation and as stated before, this project is based on the parameters of the Kepler's equation, reference [18] (see table 5.1 "Orbit parameters for SS-O with an integer number of rev in one day). Therefore, the next analysis is going use the Customer/user requirements for the orbit (step 7) and the analysis of the Kepler's equation

Table 5.1 Orbit parameters for SS-0 with an integer number of revs in one day- Table based on the Kepler's equation stated in reference [8] table 2. Baseline for the Orbit parameters in the SS-O Colombian Earth Observation.

ORBIT PARAMETERS FOR SS-0 WITH AN INTEGER NUMBER OF REVS IN ONE DAY			
Rev per Day, #	Orbital Period, seconds	Equatorial Altitude, Km	Distance between Adjacent GTs, Km
12	7200.00	1680.86	3339.59
13	6646.15	1262.09	3082.69
14	6171.43	893.79	2862.50
15	5760.00	566.89	267 1.67
16	5400.00	274.42	2504.69

The next table (Table 5.2) is a list of variables and constants definitions which have the purpose of allowing an understanding of their corresponding values for the Equations development in the next parts of the Analysis see table 5.2 “”. Refer to this table for definition information:

Table 5.2 Definition of constants or variables- Definition taken from reference [18], for the information and guidance in the Equation analysis and calculous.

DEFINITION OF CONSTANTS OR VARIABLES- ORBIT PARAMETERS ANALYSIS	
Constant or variable	Meaning/Value
P	Nodal Period.
D	Number of days in a repeat cycle.
R	Number of revs in the cycle.
J_2:	Zonal harmonic coefficient, with a value for earth equal to 0.001 082 63.
$\boldsymbol{i}$:	Inclination
$\boldsymbol{a}$:	Semi-major axis
$\boldsymbol{e}$:	Eccentricity
$\boldsymbol{\mu}$:	Earth’s gravitational constant
$\boldsymbol{\Omega}$˙:	Precession rate
GTS:	Distance between adjacent ground tracks,
$\boldsymbol{a_e}$:	Equatorial radius
p	Orbit parameter (the semi-latus rectum)
n	Mean motion

4. Nodal period & Orbital Size

4.1. Nodal period: For the calculous of the nodal period, the equation (2) according to the SS-O mission design handbook [18] is the one that is shown and explained below:

$$P = 86400 * \left(\frac{D}{R}\right) \qquad Eq.(2)$$

The number of **86400** defines the length of the mean solar day, which is at 86400 seconds (s) [18] (seconds in one day). (Seconds in on day length). Nodal period for the 14 revs demonstration (data shown in table 5.1) using the equation number 2:

D= 1 day
R= 14 revs (s)

$$P = 86400 * \left(\frac{1}{14}\right) = 6171.43\ s.$$

$$\boldsymbol{P = 6171.43\ s.}$$

4.2. Orbital Size: The Orbital Size is determined by the Eccentricity (table 4.6). In accordance with the reference of the FAA Handbook for "Describing Orbits", Classic Orbital Elements (COEs) [27] and the SS-O, design handbook [8]. In a few words, the orbital eccentricity (or eccentricity) is a measure of how much an elliptical orbit is 'squashed'. It is one of the orbital elements that must be specified in order to completely define the shape and orientation of an elliptical orbit [41].

The equation for the Eccentricity calculous varies from the type of orbit and for this type of simulation the condition of the eccentricity is to be equal **zero** (using the reference of a frozen orbit and a SS-O [18] with the aim of setting up a baseline for a future preliminary analysis in further projects. This condition along with altitude and the equation for the perturbations due to a non-spherical Earth-precession rate "Ω" (3) allows a better understanding to the altitude vs inclination behavior as shown in figure 5.2 "Sun-Synchronous Condition: Inclination vs. Altitude (e=0)"

There is need to understand that the period is a data input for the Orbit simulation, it is a basic data input in the STK model as it is shown in figure 5.2. Period of "**6171.43** sec" and Eccentricity of "**zero**". This conditions are the baseline for the STK simulation with the parameters of the Nodal period and eccentricity. See figure 5.2. "Sun-Synchronous Condition: Inclination vs. Altitude (e=0)" and figure 5.3" Orbit Period, Eccentricity, and Inclination", data equations:

$$\mathrm{p} = a(1 - e^2); \qquad \mathrm{n} = \sqrt{\frac{\mu}{a^3}}$$

$$\dot{\Omega} = -\frac{3}{2} J_2 \left(\frac{a_e}{p}\right)^2 n * \cos(i) \quad Eq.(3)$$

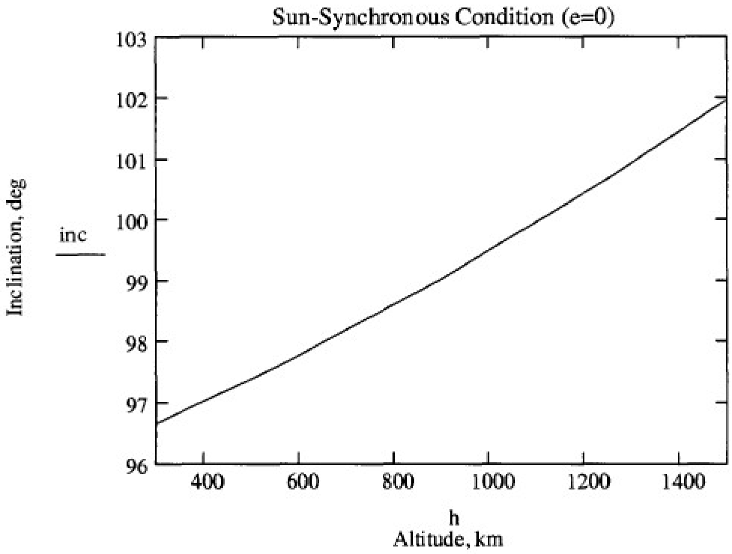


Figure 5.2 Sun-Synchronous Condition: Inclination vs. Altitude (e=0), figure taken from SS-O design, section III, "Selecting the Precession Rate" [18].
Source: Author

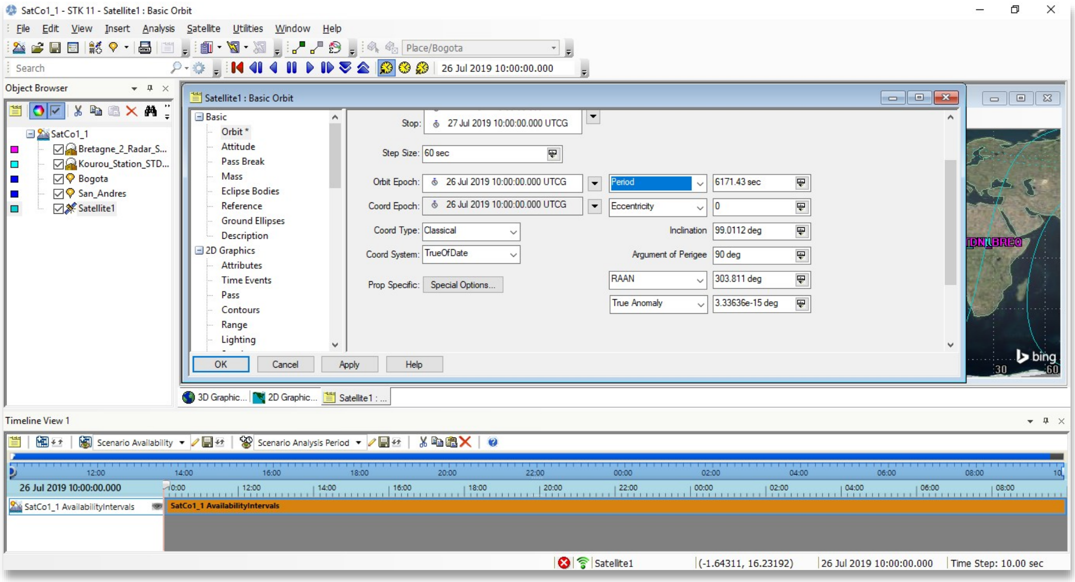


Figure 5.3 Orbit Period, Eccentricity, and Inclination, SS-O selection and data input in STK program for the Satellite simulation – Orbit data based on reference [18].

Source: Author

4.3. <u>Altitude-semi-major axis and Perigee:</u> For the analysis and simulation of the Altitude-Perigee and Apogee, the table 5.1 is going to be used as reference as well for the accomplishment of the SS-O condition s design, accomplishment of altitude requirements.

The altitude calculous is represented in the equation number (4) “Orbital altitude” is going to be used and the plotting represented with the inclination (Figure 5.2). Likewise, it is needed to remember that the requirement of altitude of a SS-O has already been stated as the ranges are between 500 to 1000 km

$$\text{h} = (a_e - a) \qquad (4)$$

$$a = \sqrt[3]{\mu\left(\frac{P}{2\pi}\right)^2}$$

$$\frac{2\pi * a_e}{R} = GTs \quad or \qquad a_e = \frac{GTs * R}{2\pi} \qquad (5)$$

4.4. <u>Semi-major axis:</u> The semi-major axis, *a*, is half of the longest diameter of an ellipse and can be calculated using the reference of the distance between adjacent ground tracks, the circumference of the earth and the revolutions. As shown in equation (5), this is needed to be calculated along with the equatorial radius

Equatorial radius: $a_e = \frac{GTs * R}{2\pi} = \frac{2862.50 * 14}{2\pi} = 6378.134344\ Km$

GTs@14 revs: 2862.50 Km (Kepler’s equation, table 5.1)

R: 14

P= 6171.43 s

$$\boldsymbol{a_e = 6378.134\ Km}$$

Semi-major axis:_ $\boldsymbol{a} = \sqrt[3]{\mu\left(\frac{P}{2\pi}\right)^2}$

$$\boldsymbol{a = 7271.9270\ Km}$$

Hence, the altitude value is:

$$\mathrm{h} = (7271.9270 - 6378{,}134) = \boldsymbol{893.79\ Km}$$

The data above matches to the data gathered in the table 5.1 "Orbit parameters for SS-0 with an integer number of revs in one day" as for the calculous of the orbit parameters with the Kepler's equations. Likewise, the simulation is performed and the data input allowed the SS-O analysis in STK as it is shown in the figures 5.4.1 "Altitude-perigee and semi-major axis data input" and 5.4.2. "Altitude-perigee and semi-major axis data input 3D model,"

The figure 5.4.1 represents the orbit data input in the STK data input. The data for the altitude is calculated by the system and is determined by the parameters of the orbit (perigee, apogee, eccentricity) for a SS-O. See figure 5.4.1 "Altitude-perigee and semi-major axis data input".

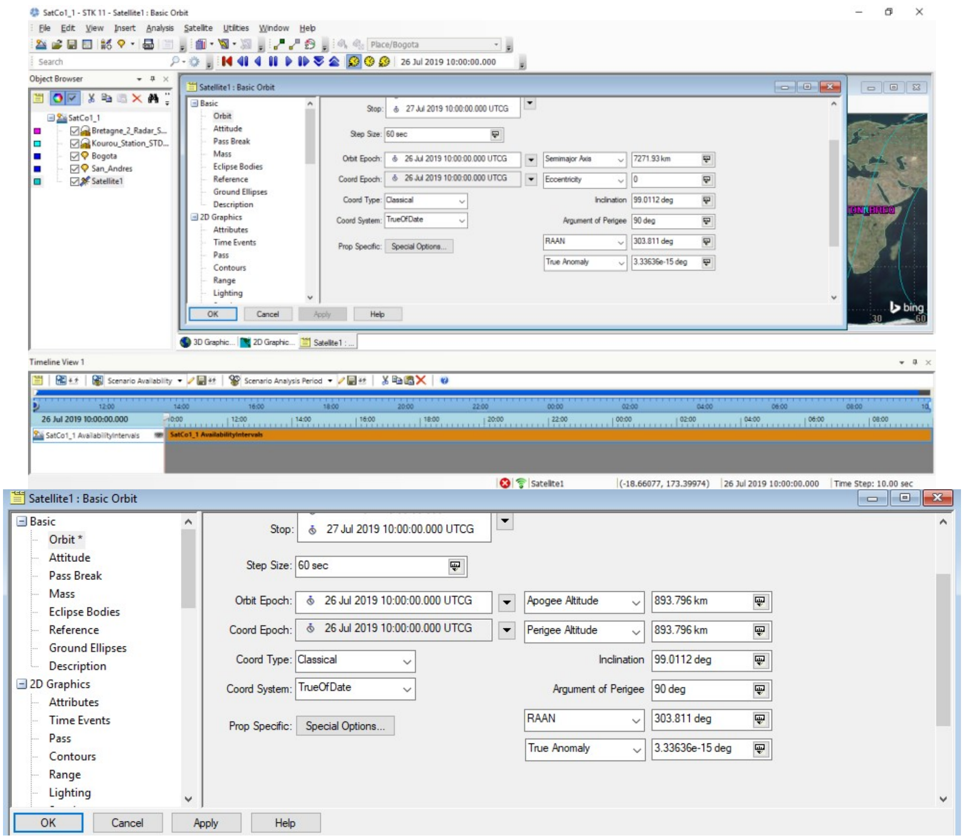


Figure 5.4.1 Altitude-perigee and semi-major axis data input, Data input of semi-major axis, eccentricity and argument of perigee by 90 º as for a sun-synchronous Orbit.

Source: Author

With the data input along with other parameters, the analysis is performed with the modeling and the figure 5.4.2 below is the 3D modeling with the data result of the simulation, this allows seeing the relationship between the theoretical analysis and the program simulation corresponding to the parameters selection. See figure 5.4.2 “Altitude-perigee and semi-major axis data input 3D”

Figure 5.4.2 Altitude-perigee and semi-major axis data input 3D model, Data input of semi-major axis, eccentricity and argument of perigee by 90 º as for a SS-O.

Source: Author

4.5. <u>Mean Motion-Revs per day</u>: The revolutions per day or mean Motion has been chosen using the reference of the Kepler’s equation, which data is stated in table 5.1 and used in the equation 2. This is a data input for the simulation as shown in the figure 5.5 “Mean Motion-Revs per day data”.

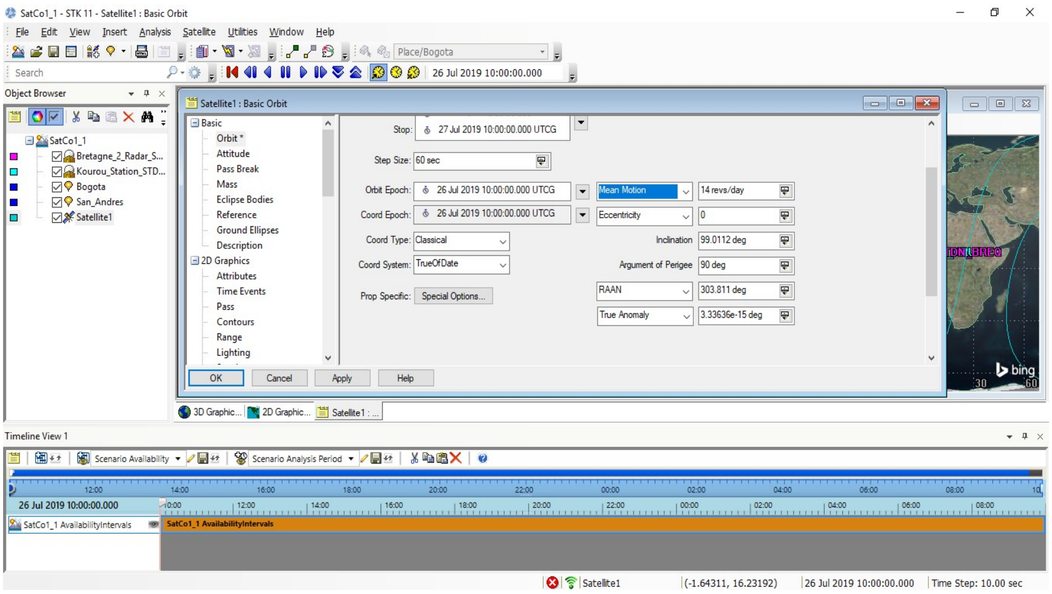


Figure 5.5 Mean Motion-Revs per day data input, data input using the Kepler’s equation from reference [18].

Source: Author

The mean motion is also simulated with the other data input (discussed above), creating a scenario parameter of observation, in this case being the Colombian Earth Surface, this allowed a simulation of the satellite going over it and gathering the data, see figure 5.6 “Mean Motion-Revs per day data input 3D”.

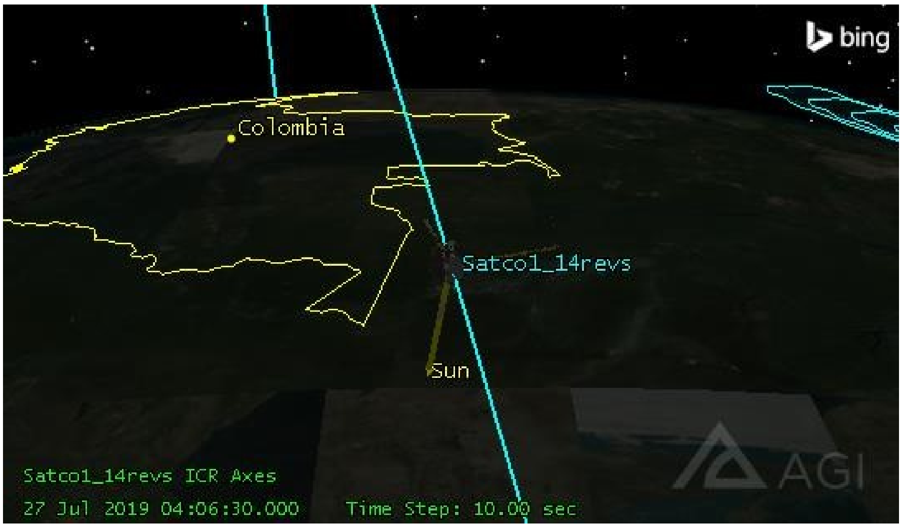
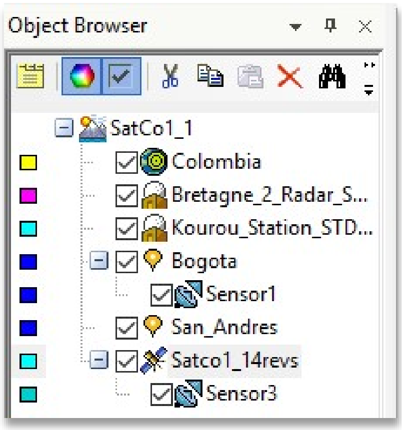


Figure 5.6 Mean Motion-Revs per day data input 3D modeling, data input using the Kepler’s equation from reference [18].

Source: Author

5. Ground position knowledge

In this part of the chapter, the Ground (position) knowledge takes place, this information is the complied along with the STK design and this information is divided into the 3D model and data analysis. Next to the data obtained for the orbit elements (Time, Semi-major Axis, Eccentricity, Inclination, RAAN, argument of Perigee, True Anomaly and Mean Anomaly), compared to the orbital parameters calculated in the point 2 and 3 of this document. This information is going to be reviewed one by one (image by image) and the data obtained in figure 5.7.



The Object browser represents the different parameters used in the simulation, which are:

1. <u>Colombia:</u> Is the area target selected (Colombian Earth surface), see image 5.7.1

2. <u>Radar station:</u> Radar Bretagne- located in Kourou ever since the closest ground station to Colombia is found in this city of the French Guyana, see image 5.7.2

Figure 5.7 Object browser, **source: Author**

3. Facility: Facility used as the nearest ground station to Colombia in Kourou, French Guyana, see image 5.7.2

4. Bogotá: This is a place of observation data handling idealized for a radar place and future ground station, see image 5.7.3.

    4.1. Sensor: Sensor idealized to be used as for the Earth observation located in Bogotá, see image 5.7.3.1.

5. San Andres: This is a place of observation data handling idealized for a radar place and future ground station, see image 5.7.3

6. Satellite: This is the satellite simulation as for the Earth Observation in a SS-O, see figure 5.7.4

    6.1. Sensor: Sensor idealized to be used as for the Earth observation used in San Andres, see image 5.7.4.1.

7. Full simulation: The full simulation in 2D and 3D is represented in this part, see image 5.7.5

6. Resolution

This section stands for the two types of resolution elements focused on this project scope, the Spatial resolution and Revisit as shown below:

6.1. Spatial Resolution: The space resolution is the resolution is determined by a simple equation according to the Digital Globe Platform [40]: the larger the optics and the lower the sensor, the higher the resolution, the equation (6) is the representation of this parameters:

$$Resolution = \frac{height}{focal\ lenght} x\ detector\ size \qquad (6)$$

This is the type of theoretical analysis, however, this parameter has already been given from the Customer/User requirements (chapter 4, step 7.3) and in accordance to the Colombian Observation needs, it is needed:

From 1.25 m to 2.5 m in panchromatic, 5 to 10 in multispectral. (Up to 20-30 m scale resolution). Taken from the Requirement **(QF-T02),** see table 4.8.

6.2.Revisit (time to point same location): The revisit time has already been determined in chapter 4. Step 7.3 and the value is of 15 days as part of the fulfillment of the Customer/User requirements.

These parameters of resolution are illustrated by means of the 2D and 2D modelling, in a time of 24 h, the remote sensing for the area of observation sis shown in figure 5.8 "revisit and spatial resolution for the Colombian Earth Surface" and as the data obtained in the 3D model as shown in figure 5.9.5: "Full simulation in 3D"

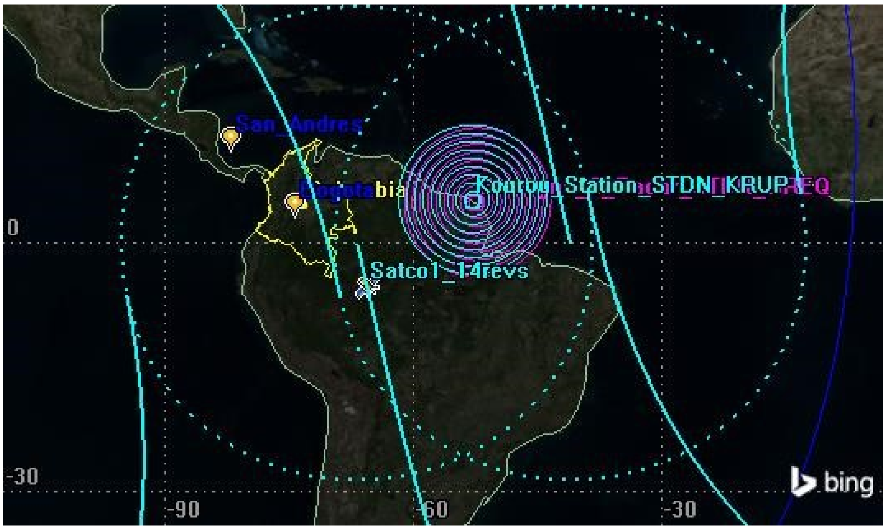


Figure 5.8 SS-O, revisit and spatial resolution for the Colombian Earth Surface. Source: Author

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5.2. ANALYSIS OF RESULTS

As part of the mission design, in this section of the chapter 5, the results obtained from the parameters definition and calculous used on the STK modeling program, they are discussed as every factor represented in figure 5.7 "Object Browser"

1. **Colombia**: Is the area target selected (Colombian Earth surface), see image 5.9.1, The Colombian surface is the main focus of this mission design as in accordance with the SatCo1 Objectives. Likewise, this area is supported with the reference [14] surface data researched for the Colombian Surface information, as discussed in step 7.4 from the chapter 4, see figure 5.9.1.

1.

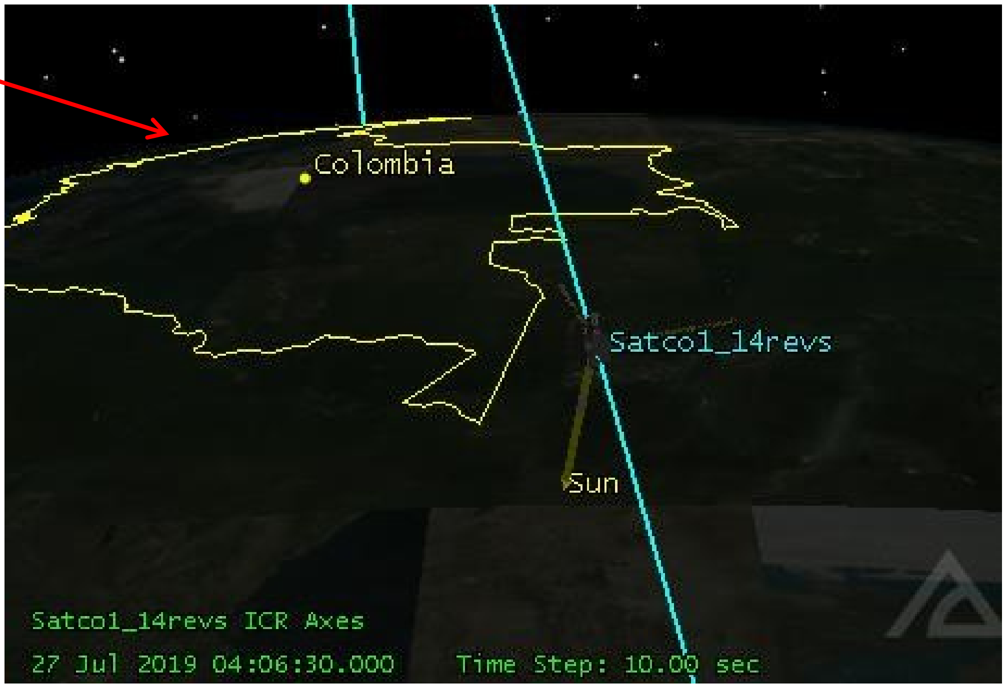

Figure 5.9.1 Area target selected (Colombian Earth surface)-
Source: Author

The data obtained in the STK matches to the Colombian Earth surface and it was successfully applied as the area of observation in accomplishment with the requirement **QFUR01** (See Table4.8).

2. **Radar station:** The radar station has been chosen to be working in the location of the Bretagne radar [47]- located in Kourou station ever since the closest ground station to Colombia is located in the French Guyana, see figure 5.9.2

3. **Facility:** The ideal facility may be located in Colombia but ever since there is no a ground station established yet in the Country, the closest ground Facility is the one located in Kourou from the French Guyana, in addition, the radar station is located in the same city. see image 5.9.2

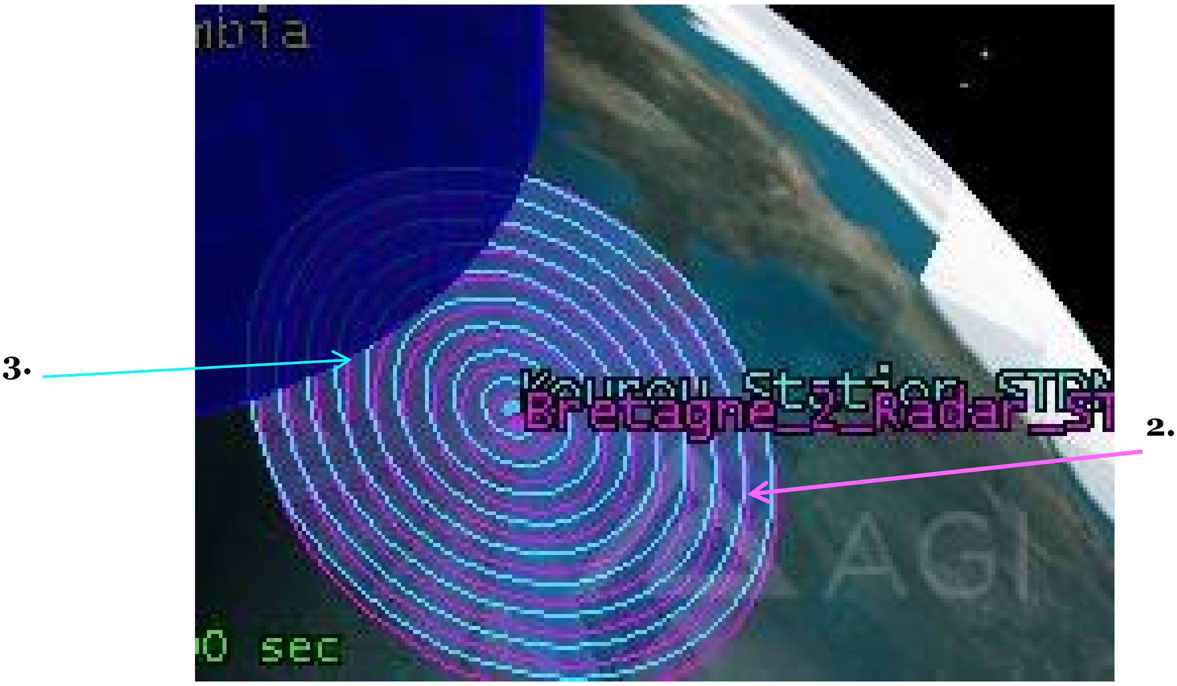

Figure 5.9.2 Radar station Bretagne and ground station in the French Guyana

Source: Author

The data offered in the STK program, allowed inserting the ground station and the radar in Kourou, French Guyana, this will work along with the sensors located in Colombia and they compile the information as in fulfillment of the requirements **QF-T01** & **QFUR10** (See Table4.8).

4. **Bogotá:** Bogotá is one idealized place of observation data handling ever since this City is located almost in the geological center of Colombia and it is closed to different types of antennas, receptors that could work along with the Satellite. See image 5.9.3.2 "Idealized place of observation data handling (Bogotá & San Andrés)"

   4.1. Sensor1: This is an idealized Sensor to be used as for the Earth observation located in Bogotá and shall collect the data received (sensed) from the Satellite and will be redirected to the Ground station, see image 5.9.3.1.

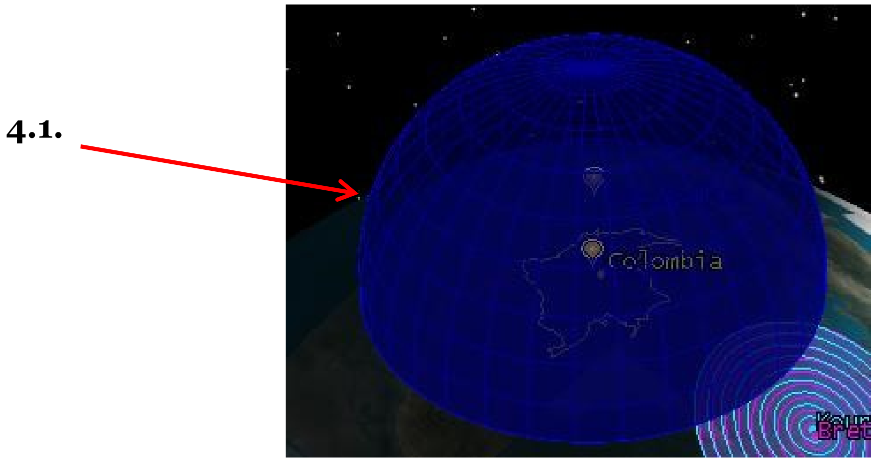

Figure 5.9.3.1 Sensor idealized to be used as for the Colombian Earth observation
Source: Author

This sensor was inserted in the STK program and worked as a point of data sensing of the information gathered in table 5.4" Satellite-Satco1_14revs: Orbit parameters- Simulation data" as in accomplishment of the requirement **QF-T01** & **QFUR10** (See Table4.8).

5. **San Andrés:** The data offered in the STK program, allowed inserting the ground station and the radar in Kourou, French Guyana, this will work along with the sensors located in Colombia and they compile the information as in fulfillment of the requirements **QF-T01** & **QFUR10**. (See Table4.8)

Figure 5.9.3.2 Idealized place of observation data handling (Bogotá & San Andrés)
Source: Author

The Idealized places of observation were inserted in the STK program as

"Place" as reference for a radar and ground station in the future Colombia Space technologies advances, this was performed as in accordance to the requirements **POR03, PCO0** and element **MIE04,** (see chapter 2) and table 4.8.

6. **Satellite**: This is the satellite used for the SS-O in the Colombian Earth Observation adjusted to the place of observation (Colombia), the period and time of the mission requirements, see figure 5.9.4

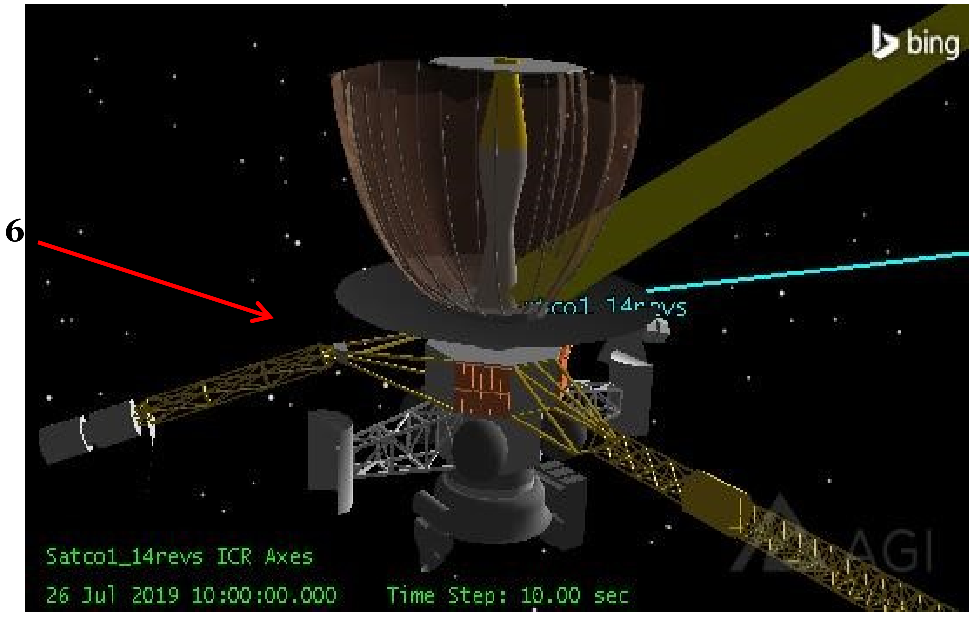

Figure 5.9.4 Satellite simulation for the Earth Observation in a SS-O
Source: Author

This type of satellite was taken from the data of the STK modeling program, however, this should be modeled and inserted to the program so the whole interfaces and physical requirements for the Satellite are properly established and adjusted to the Colombian needs as part of a future case of study, in accordance with the Payload requirements.

6.1.Sensor2: This is an idealized Sensor to be used as for the Earth observation located in the SatCo1 (satellite) and shall collect the data of the payload (images and observation data) received and it is sensed with the sensor1. Located in Bogotá and redirected to the Ground station, see image 5.9.4.1 "Satellite simulation as for the Earth Observation in a SS-O" for the data collected, see table 5.4" Satellite-Satco1_14revs: Orbit parameters"

6.1.

Figure 5.9.4.1 Satellite simulation as for the Earth Observation in a SS-O
Source: Author

This type of sensor just as the satellite design. was taken from the data of the STK modeling program, however, this should be adjusted and inserted to the program so the whole interfaces and physical requirements for the Satellite are properly established in regards to the types of sensors of a satellite observation. Even though this is not taken into account on this project scope, this can be a baseline for a future research of the Sensors of a Colombian Earth Observation satellite as in accordance with the Data handling and processing requirements.

7. **Full simulation:** This section is for the full simulation of the program with the parameters and Orbital elements established in 2D and 3D is represented in this part, see image 5.9.5, "Full simulation in 2D and 3D respectively".

This image represents the graphics obtained with some input/output data of the whole information supported in the previous parts (1 to 6) and they are successfully simulated in the STK program.
This section has been performed in accordance with the whole requirements section review of the Orbit and satellite simulation exposed in table 4.8. Likewise, this is baseline of the simulation review (section 5.3 of this chapter) and the conclusions shown in chapter 6.

2D

3D

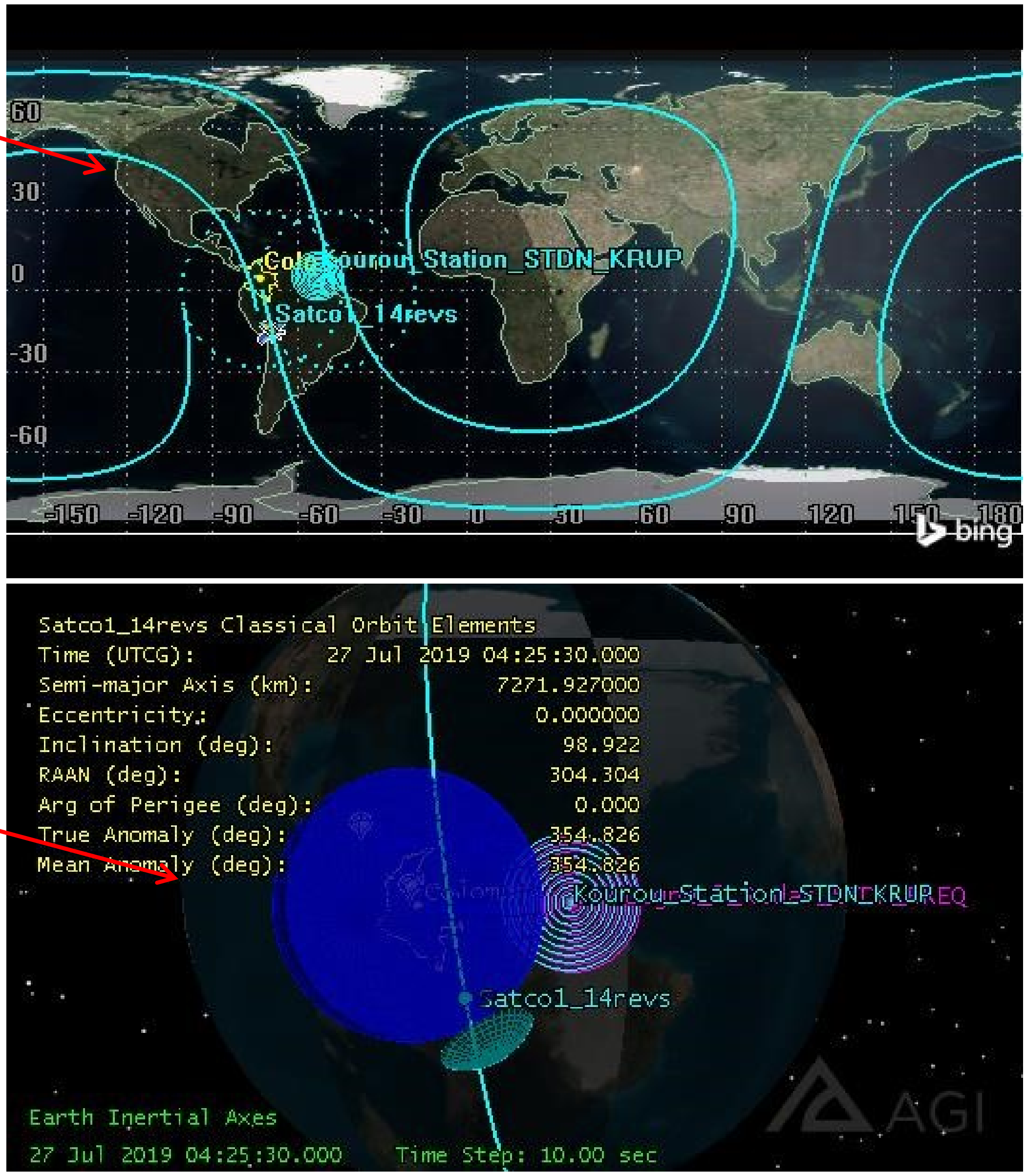

Figure 5.9.5 Full simulation in 2D and 3D respectively.
Source: Author

The previous analysis is further complemented along with the data obtained in the simulation and it is reviewed in section 5.3 “Table of Data results”.

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5.3 TABLES OF DATA RESULTS

In this section of the chapter 5, there are going to be three tables, the first one is for the theoretical data already calculated or defined (in the semi- major axis and Eccentricity). The second one is the data obtained with the STK program and the Third one the comparison (analysis of results) between the theoretical data and the STK program data, see tables below (Tables 5.3 "Satellite-Satco1_14revs: Orbit parameters- theoretical data," and 5.4 "Satellite-Satco1_14revs: Orbit parameters- Simulation data". The information obtained in the tables will be discussed in the Data results analysis, which is discussed below the tables.

Table 5.3 Satellite-Satco1_14revs: Orbit parameters- theoretical data, previously calculated or data given by the requirements

SATELLITE-SATCO1_14REVS: ORBIT PARAMETERS- THEORETICAL DATA (TD)	
Semi-major Axis (km)	**Eccentricity**
7271.927	0.0

Table 5.4 Satellite-Satco1_14revs: Orbit parameters- Simulation data, data obtained with the STK program for the Orbit parameters- J2000 Classical Orbit Elements

SATELLITE-SATCO1_14REVS: ORBIT PARAMETERS- SIMULATION (SD)							
Time (UTCG)	**Semi-major Axis (km)**	**Inclination (deg)**	**RAAN (deg)**	**Arg of Perigee (deg)**	**Eccentricity**	**True Anomaly (deg)**	**Mean Anomaly (deg)**
26 Aug 2019 00:00:00.000	7271.927000	0.000000	98.922	323.643	0.000	32.952	32.952
26 Aug 2019 01:00:00.000	7271.927000	0.000000	98.922	323.684	0.000	242.715	242.715
26 Aug 2019 02:00:00.000	7271.927000	0.000000	98.922	323.725	0.000	92.479	92.479
26 Aug 2019 03:00:00.000	7271.927000	0.000000	98.922	323.765	0.000	302.242	302.242
26 Aug 2019 04:00:00.000	7271.927000	0.000000	98.922	323.806	0.000	152.005	152.005

SATELLITE-SATCO1_14REVS: ORBIT PARAMETERS- SIMULATION (SD)							
Time (UTCG)	**Semi-major Axis (km)**	**Inclination (deg)**	**RAAN (deg)**	**Arg of Perigee (deg)**	**Eccentricity**	**True Anomaly (deg)**	**Mean Anomaly (deg)**
26 Aug 2019 05:00:00.000	7271.927000	0.000000	98.922	323.847	0.000	1.768	1.768
26 Aug 2019 06:00:00.000	7271.927000	0.000000	98.922	323.887	0.000	211.531	211.531
26 Aug 2019 07:00:00.000	7271.927000	0.000000	98.922	323.928	0.000	61.295	61.295
26 Aug 2019 08:00:00.000	7271.927000	0.000000	98.922	323.969	0.000	271.058	271.058
26 Aug 2019 09:00:00.000	7271.927000	0.000000	98.922	324.009	0.000	120.821	120.821
26 Aug 2019 10:00:00.000	7271.927000	0.000000	98.922	324.050	0.000	330.584	330.584
26 Aug 2019 11:00:00.000	7271.927000	0.000000	98.922	324.091	0.000	180.347	180.347
26 Aug 2019 12:00:00.000	7271.927000	0.000000	98.922	324.131	0.000	30.111	30.111
26 Aug 2019 13:00:00.000	7271.927000	0.000000	98.922	324.172	0.000	239.874	239.874
26 Aug 2019 14:00:00.000	7271.927000	0.000000	98.922	324.213	0.000	89.637	89.637
26 Aug 2019 15:00:00.000	7271.927000	0.000000	98.922	324.253	0.000	299.400	299.400
26 Aug 2019 16:00:00.000	7271.927000	0.000000	98.922	324.294	0.000	149.163	149.163
26 Aug 2019 17:00:00.000	7271.927000	0.000000	98.922	324.335	0.000	358.926	358.926
26 Aug 2019 18:00:00.000	7271.927000	0.000000	98.922	324.375	0.000	208.690	208.690
26 Aug 2019 19:00:00.000	7271.927000	0.000000	98.922	324.416	0.000	58.453	58.453
26 Aug 2019 20:00:00.000	7271.927000	0.000000	98.922	324.457	0.000	268.216	268.216
26 Aug 2019 21:00:00.000	7271.927000	0.000000	98.922	324.497	0.000	117.979	117.979
26 Aug 2019 22:00:00.000	7271.927000	0.000000	98.922	324.538	0.000	327.742 s	327.742
26 Aug 2019 23:00:00.000	7271.927000	0.000000	98.922	324.579	0.000	177.506	177.506
26 Aug 2019 23:59:00.000	7271.927000	0.000000	98.922	324.619	0.000	23.773	23.773

Table 5.5 Satellite-Satco1_14revs: Orbit parameters- Simulation & theoretical data, comparison- results analysis by percentage of accuracy.

SATELLITE-SATCO1_14REVS: ORBIT PARAMETERS- THEORETICAL AND SIMULATION					
Semi-major Axis (km)	**Semi-major Axis (km)**	**% of accuracy**	**Eccentricity**	**Eccentricity**	**% of accuracy**
7271.927	7271.927000	100 %	0	0.000	100 %

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DATA RESULTS ANALYSYS:

The data results analysis is represented in the lines below, focusing on the Whole analysis of the data obtained and the requirements baseline of this project:

- The results of this analysis along with the simulation were successfully compared as shown in table 5.5 "Satellite-Satco1_14revs: Orbit parameters- Simulation & theoretical data,", the comparison was performed using the data of the orbits parameters of the se mi major axis and Eccentricity achieved a 100 % of accuracy of the data obtained in the program. however, more data is obtained with the program and it can be further studied in a preliminary design.

- A concept baseline has been established, this allowed having the main concepts description for a conceptual design on the aerospace field and the systems engineering. Determining the system engineering parameters for the Conceptual process finally led to a systematical analysis reviewed in this chapter with the STK simulation. The data obtained during 24 h fits to the Main requirements of Orbital Elements, Coverage and Data handling as in accordance with the requirements of table 4.8.

- During the process of defining the Customer/user needs & requirements research as part of the preliminary requirements review, the areas of application of the Earth Observation allowed conceiving the needs and main functional requirements for the Colombian Earth Observation, defining the PND and the CCE as the customer and user respectively. Likewise, it was found the importance of having access to images in different weather conditions such as the cloudiness as fundamental part of the mission development.

- This project has the scope of defining the conceptual design phases using the Space engineering standard ECSS-E-ST-10C, however, the project was intended to also show an analytical-practical simulation to show the application of the requirements defined. This was successfully performed and analyzed showing the relationship of the Kepler's equation in a theoretical analysis and a STK program simulation, understanding the basis of this analysis as the objective of allowing a pre step for a preliminary design (phase B and C), which come with the calculous and simulation.

CHAPTER 6 – CONCLUSIONS

- The conceptual design for an Earth Observation Satellite of the Colombian Surface has successfully been made using the Space engineering standard ECSS-E-ST-10C, while working on the phase zero “Mission analysis”, phase A “Feasibility” and giving a preliminary advance to the phase B “preliminary definition”. This has been performed by means of creating the Mission design review (MDR), Preliminary requirements review (PRR), Systems requirements review (SRR) and an approach to the Preliminary design review (PDR).

- The main Colombian needs regarding to Earth Observation were successfully established using the PND and the CCE references, being those the desired Customer and User of this project. These needs found that despite of the cloudiness issues in the country, it was considered a priority the usage of technologies of multispectral optical satellites, which was compiled as a requirement of the payload itself.

- A mission definition review was performed and achieved with a mission design; this allowed a preliminary review of the functional and operational requirements, mission characterization, elements, data needed and performance with relevant information to the Conceptual process and Mission analysis. This allowed the further research on the Requirements baseline procedures and used during the whole mission development.

- The Preliminary systems, main subsystems and requirements were established as in accordance to the Colombian Earth Observation needs from the Earth Observation Magazine [13] and the CCE reference. Hence, it allowed understanding the principal information required for a requirements baseline set-up. Likewise, this research can be used in further projects as reference to the Colombian Satellite observation and remote sensing and can be adapted to the needs using the systematical phases shown throughout the project by replacing updated information.

CHAPTER 7 – RECOMMENDATIONS

This section is for the recommendations that are defined by the constraints, learning and future works, this is based on the whole research process. Along with the using of the different references required for the SatCo1 project development and this is defined lines below.

7.1 Constraints

Some constraints of this Graduation project were mainly affected by the lack of space projects/documents/researches focused on the Colombian Earth surface or even from the stakeholder matters, such difficulties were:

- Not enough information of specific researches on the Colombian Earth Observation by means of Low Earth Orbits, in one hand the applications and needs were found as in reference [13]. On the other hand, there were not found any similar projects related to the Satco1 objectives.

- It is not clear whether the CCE still works, there are some projects reflected from previous years but there is not enough evidence of its current work.

- It is been identified that for developing any space mission design it is needed to understand different processes and phases of the System engineering, which at the beginning was hard to understand.

7.2 Learning

Throughout this project, a lot regarding Earth Observation/SS-O/Applications and Standards has been learnt, using the practical learning and the research steps, which allowed the learning on:

- The use of systematical processes and phases for space missions Specially "Artificial Satellite projects" have been learnt using the Systems Engineering, the SMAD book and the standard ECSS-E-ST-10C.

- Identifying the needs of the Colombian Earth Observation such as for the Land use and growth and the importance of having an own System that allows different sectors to access to this data, with the aim of not renting from others and creating a local growth of the Space for the Colombian matters.

- Practical means such as simulations for integrating the Whole requirements definition, especially for the Orbital Elements, along with the respective interpretation and understanding of the Function on an Artificial earth Observation Satellite on the Colombian Surface.

7.3 Future Works

This project is intend to be a reference and allow future works in the Colombian space matters and other similar projects such as:

- A preliminary design, verifying the Conceptual process and performing the corrections for an Earth Observation Satellite focused on the Colombian needs.

- Subsystems architectural design and system integration simulation for an artificial satellite for the specifications related to the mission. Along with a specific deployment of the elements of every subsystems of the system (satellite)

- Future researches/designs/architectures for related mission projects that may be implemented with this design such as ground facilities, space launch systems, rockets, remote sensors, and a huge variety of devices needed for the Colombian and worldwide space researches.

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