MINISTÉRIO DA CIÊNCIA, TECNOLOGIA, INOVAÇÕES E COMUNICAÇÕES
INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS

sid.inpe.br/mtc-m21b/2017/03.17.13.44-TDI

SPSYSE-TK: A METHODOLOGY FOR SPACE SYSTEMS ENGINEERING BASED ON THE PROCUREMENT OF TURNKEY SATELLITES

Gabriel Gustavo Coronel Mariño

Master's Dissertation of the Graduate Course in Space Engineering and Technology/Space Systems of Management and Engineering, guided by Drs. Geilson Loureiro, and Otávio Luiz Bogossian, approved in March 31, 2017.

URL of the original document:
<http://urlib.net/8JMKD3MGP3W34P/3NH9NJ5>

INPE
São José dos Campos
2017

PUBLISHED BY:

Instituto Nacional de Pesquisas Espaciais - INPE
Gabinete do Diretor (GB)
Serviço de Informação e Documentação (SID)
Caixa Postal 515 - CEP 12.245-970
São José dos Campos - SP - Brasil
Tel.:(012) 3208-6923/6921
Fax: (012) 3208-6919
E-mail: pubtc@inpe.br

sid.inpe.br/mtc-m21b/2017/03.17.13.44-TDI

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São José dos Campos
2017

Cataloging in Publication Data

Coronel Mariño, Gabriel Gustavo.

C816s SPSYSE-TK: a methodology for space systems engineering based on the procurement of turnkey satellites / Gabriel Gustavo Coronel Mariño. – São José dos Campos : INPE, 2017.

xxvi + 304 p. ; (sid.inpe.br/mtc-m21b/2017/03.17.13.44-TDI)

Dissertation (Master in Space Engineering and Technology/Space Systems of Management and Engineering) – Instituto Nacional de Pesquisas Espaciais, São José dos Campos, 2017.

Guiding : Drs. Geilson Loureiro, and Otávio Luiz Bogossian.

1. Systems engineering. 2. Space systems. 3. Turnkey satellites. 4. Space missions. I.Title.

CDU 629.78

Aluno (a): ***Gabriel Gustavo Coronel Mariño***

Título: **"SPSYSE-TK: A METHODOLOGY FOR SPACE SYSTEMS ENGINEERING BASED ON THE PROCUREMENT OF TURNKEY SATELLITES".**

Aprovado (a) pela Banca Examinadora em cumprimento ao requisito exigido para obtenção do Título de *Mestre* em

Engenharia e Tecnologia Espaciais/Eng. Gerenc. de Sistemas Espaciais

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( ) maioria simples

(X) unanimidade

São José dos Campos, 31 de Março de 2017

“If you can’t explain it simple, you don’t understand it well enough”.

Albert Einstein

ACKNOWLEDGMENTS

A mi familia, quienes me dieron todos los valores, las herramientas y el apoyo necesario para estar donde estoy, superar cada uno de los retos que he encontrado, y sentir confianza que solo cosas buenas vendrán en el futuro.

A mi esposa, quien cada día me brinda un apoyo incomparable para alcanzar mis metas y con quien he compartido un gran número de aventuras y experiencias.

A mis amigos, quienes por más lejos que estén son siempre ejemplos de superación.

Aos meus colegas e amigos do LSIS, que têm sido de grande ajuda e fonte de interessantes e valiosas discussões não só de engenharia de sistemas como também de muitas outras áreas da vida.

Aos meus orientadores, que me ajudaram a transformar ideias vagas em um trabalho do qual me sinto satisfeito e tenho certeza que pode ser útil.

Ao LIT, ao INPE e a todos os profissionais que aí trabalham, que de alguma forma contribuíram para o desenvolvimento deste trabalho.

À CAPES, que deu o apoio financeiro para cursar este mestrado.

ABSTRACT

Latin American countries, such as Venezuela, Mexico, Peru, and Brazil, have recently implemented space systems based on procured satellites from more experienced manufacturers. On the other hand, systems engineering has demonstrated to be an ideal approach to solve problems that involve complex solutions, such as space systems. Literature review showed that traditional systems engineering approach should change when the procurement of previous developed elements is considered. In these cases, the market imposes restrictions on the solution, and thus, feedbacks, iterations, and trade-offs should be performed between what is wanted and what exists. Consequently, this work proposes a methodology for space systems engineering based on the procurement of turnkey satellites (i.e. 'pre-specified' satellites), which are available on the market and that potentially, as occurs with commercial products in other industries, might result in the implementation of space systems at lower costs and in shorter times with respect to space systems in which all their elements must be developed. The proposed methodology, which is called SPSYSE-TK, aims to guide the development of space systems based on traditional systems engineering activities that have been adapted to take into account the issues and restrictions that commercial products impose on the solution to a given problem. This enables translating a set of customer and other stakeholders needs into a space system while considering the limitations that are imposed by the turnkey satellites on such space system as well as the existing characteristics of such satellites that can be exploited. The SPSYSE-TK methodology brings to the space industry practices that have been identified in other industries and have been catalogued as appropriate for performing systems engineering while accommodating commercial products. Specifically, the SPSYSE-TK methodology proposes a set of phases, processes, and activities, which have been particularly established for specifying space systems based on the procurement of turnkey satellites. The SPSYSE-TK methodology is exemplified and compared with respect to the traditional space systems engineering methodology of the ECSS that is used for the development of systems conceived for a particular mission. The SPSYSE-TK methodology showed to be more appropriate than the ECSS methodology for space projects based on the procurement of turnkey satellites.

Keywords: Systems engineering. Space systems. Turnkey satellites. Space missions.

METODOLOGIA PARA ENGENHARIA DE SISTEMAS ESPACIAIS BASEADOS NA AQUISIÇÃO DE SATÉLITES *TURNKEY*

RESUMO

Recentemente os países latino-americanos, tais como a Venezuela, o México, o Peru e o Brasil têm implementado sistemas espaciais baseados na aquisição de satélites de fornecedores mais experimentados. Por outro lado, a engenharia de sistemas tem mostrado ser a abordagem ideal para solucionar problemas que precisam de soluções complexas, tais como sistemas espaciais. A revisão bibliográfica feita revelou que a abordagem tradicional de engenharia de sistemas deve mudar quando considerar a aquisição de elementos previamente desenvolvidos. Desta forma, o mercado impõe restrições sobre a solução e, consequentemente, realimentações, iterações e trade-offs devem serem realizados entre o que se quer e o que existe. Esta dissertação propõe uma metodologia para o desenvolvimento de sistemas espaciais baseado na aquisição de satélites *turnkey* (ou satélites "pré-especificados") que estão disponíveis no mercado e que potencialmente, como ocorre com produtos comerciais em outras indústrias, poderiam resultar na implementação de um sistema espacial de menor custo e em tempos mais curtos que um sistema espacial no qual os elementos precisam ser desenvolvidos. A metodologia proposta, chamada SPSYSE-TK, visa guiar esse desenvolvimento de sistemas espaciais, utilizando atividades tradicionais da engenharia de sistemas as quais têm sido adaptadas para levar em conta as questões e restrições que produtos comerciais impõem na solução de um dado problema. Isto permite traduzir um conjunto de necessidades do cliente e de outros interessados em um sistema espacial enquanto são levadas em conta as limitações que os satélites *turnkey* impõem sobre ele bem como o aproveitamento de características existentes nesses satélites. Igualmente, a metodologia SPSYSE-TK traz para a indústria espacial práticas que foram identificadas em outras indústrias como apropriadas para executar engenharia de sistemas e acomodar produtos comerciais. Especificamente, a metodologia SPSYSE-TK explicita um conjunto de fases, processos e atividades que foram especialmente projetadas para especificar sistemas espaciais baseados na aquisição de satélites *turnkey*. A metodologia SPSYSE-TK é exemplificada e comparada com a metodologia tradicional de engenharia de sistemas espaciais da ECSS que é aplicada para o desenvolvimento de sistemas concebidos para uma particular missão. A metodologia SPSYSE-TK mostrou ser mais apropriada que a metodologia da ECSS para projetos espaciais baseados na compra de satélites *turnkey*.

Palavras-chave: Engenharia de sistemas. Sistemas espaciais. Satélites *turnkey*. Missões espaciais.

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LIST OF ACRONYMS AND ABBREVIATIONS

ABAE	(Venezuelan) Bolivarian Agency for Space Activities (from Spanish *Agencia Bolivariana para Actividades Espaciales*)
AEB	Brazilian Space Agency (from Portuguese *Agência Espacial Brasileira*)
AHP	Analytic Hierarchy Process
AIAA	American Institute of Aeronautics and Astronautics
AIT	Assembly, Integration, and Test
ANATEL	(Brazilian) Agency of Telecommunications Agency (from Portuguese *Agência Nacional de Telecomunicações*)
AOCS	Attitude and Orbit Control Subsystem
AR	Acceptance Review
ARD-SM	Amazon Rainforest Deforestation Surveillance Mission
ASSE	Applied Space Systems Engineering
BKCASE	Body of Knowledge and Curriculum to Advance Systems Engineering
CAN	Controller Area Network
CAPES	Coordination of improvement of higher level personnel (from Portuguese *Coordenação de Aperfeiçoamento de Pessoal de Nível Superior*)
CBERS	China-Brazil Earth Resources Satellite
CDR	Critical Design Review
CFP	Call for Proposals
CGWIC	China Great Wall Industry Corporation
CNES	(French) National Center of Space Studies (from French *Centre National d'études Spatiales*)
ConOps	Concept of Operations
COTS	Commercial Off-the-Shelf
DETER	Real Time Deforesting Detection (DETER)
DLR	German Aerospace Center (from German *Deutsches Zentrum für Luft- und Raumfahrt*)
DOD	(United States) Department of Defense
EADS	European Aeronautic Defence and Space Company
ECSS	European Cooperation for Space Standardization

EIRP	Equivalent Isotropically Radiated Power
ELR	End-of-life Review
EM	Engineering Model
EMC/EMI	Electromagnetic Compatibility/Interference
EPIC	Evolutionary Process for Integrating COTS-based systems
EPS	Electric Power Supply subsystem
ERA	Entity-Relationship Analysis
ESA	European Space Agency
FDIR	Failure Detection, Isolation, and Recovery
FMECA	Failure modes, effects, and criticality analysis
FQR	Flight Qualification Review
FRR	Flight Readiness Review
GAS	Ground Application Segment
GCS	Ground Control Segment
GPS	Global Positioning System
GSD	Ground Sample Distance
GSE	Ground Support Equipment
IAC	International Astronautical Congress
ID	Identifier
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IFB	Invitation for Bid
INCOSE	International Council on Systems Engineering
INPE	(Brazilian) National Institute for Space Research (from Portuguese *Instituto Nacional de Pesquisas Espaciais*)
IR	Infrared
ISO	International Organization for Standardization
ITAR	International Traffic in Arms Regulations
ITT	Invitation To Tender
ITU	International Telecommunications Union
IV&V	Integration, Verification, and Validation
JPEG-LS	Joint Photographic Experts Group - Lossless compression

LEO	Low-Earth Orbit
LIT	(Brazilian) Integration and Testing Laboratory
LRR	Launch Readiness Review
LSIS	(INPE/LIT) Systems Engineering Office
LTDN	Local Time of Descending Node
KARI	Korea Aerospace Research Institute
MCR	Mission Close-out Review
MDR	Mission Definition Review
MPSSDR	Mission and Preliminary Space System Definition Review
MS	Multi-spectral
NASA	(United States) National Aeronautics and Space Administration
NIR	Near-Infrared
OBDH	On-Board Data Handling subsystem
ORR	Operational Readiness Review
OTS	Off-the-Shelf
PAN	Panchromatic
PDR	Preliminary Design Review
PMDR	Preliminary Mission Definition Review
PMI	Project Management Institute
PRODES	Legal Amazon Deforesting Monitoring Project
PROP	Propulsion subsystem
PRR	Preliminary Requirements Review
QFD	Quality Function Deployment
QR	Qualification Review
RF	Radiofrequency
RFI	Request for Information
RFP	Request for Proposal
RFQ	Request for Quotation
ROM	Rough Order of Magnitude
SAR	Synthetic Aperture Radar
SE	Systems Engineering
SEMP	Systems Engineering Management Plan

SEP	Systems Engineering Plan
SGDC	(Brazilian) Defense and Strategical Communications Geostationary Satellite (from Portuguese *Satélite Geoestacionário de Defesa e Comunicações Estratégicas*)
SMAD	Space Mission Analysis and Design
SMC	(United States) Space and Missile Systems Center
SoS	System-of-Systems
SOW	Statement of Work
SPSYSE-TK	SPace SYStems Engineering methodology based on the procurement of TurnKey satellites
SRR	System Requirements Review
SSDR	Space System Definition Review
SSL	Space Systems Loral
SSO	Sun-Synchronous Orbit
SSTL	Surrey Satellite Technology Ltd.
STA	Systemic Textual Analysis
STM	Structural-Thermal Model
SWOT	Strengths, Weaknesses, Opportunities, and Threats
TBD	To Be Defined
TBC	To Be Confirmed
TC	Telecommand
TCS	Thermal Control Subsystem
TM	Telemetry
TT&C	Telemetry, Tracking, and Control subsystem
UART	Universal Asynchronous Receiver/Transmitter
USAF	United States Air Force
VENESAT	Venezuela Communications Satellite
VLM	Microsatellites Launch Vehicle (from Portuguese *Veículo Lançador de Microssatélites*)
VRSS	Venezuelan Remote Sensing Satellite
WAN	Wide Area Network
WBS	Work Breakdown Structure
WSM	Weighted Scoring Method

SUMMARY

Page

1 INTRODUCTION

This research work is about a methodology for space systems engineering based on the procurement of turnkey satellites. The methodology herein proposed is later referred as SPSYSE-TK.

Within this work, the term ‘space systems engineering’ refers to the systems engineering effort applied to transform a set of needs and constraints into a space system solution. The term ‘turnkey satellites’ refers to complete satellites (i.e. platform and payload) that are available on the market, so they can be procured from it as they are offered or with minor customized modifications. The term ‘methodology’ refers to a system of activities embodied into temporal and logical dimensions (i.e. phases and processes, respectively). The term ‘procurement’[1] refers to the act of buying. Finally, the term ‘author’ refers to the author of this work.

This chapter presents the motivation for developing this work, the objectives of this work, the approach that was followed to develop this work, and finally, the structure of this document.

1.1 **Motivation**

1.1.1 **Space projects in Latin America**

Since the 2000s, Latin American countries have been increasing their participation in space projects as they have become aware of the importance of space technology (SABATHIER et al., 2009). The number of space projects in Latin America demonstrate that its nations are carrying out big steps to have a presence in space (SANCHEZ, 2014).

[1] Procurement and acquisition are commonly considered as synonyms. However, in some systems engineering references, specially those related to the United States Department of Defense (DOD), the term acquisition involves design, construction, integration, testing, deployment, operations, support, and disposal activities (RENDON et al., 2012; SCHWARTZ, 2014). For this reason, this work avoids the use of the term acquisition for referring to the act of buying.

Furthermore, the continuous demand for satellite services in Latin America in the recent years has fueled the competition among satellite operators in the region, which have continuously expanded their fleets. In addition, national satellite programs of Latin American countries have also been growing recently. (SCHNEIDERMAN, 2015)

The majority of recent Latin American's space projects have been based on the procurement of satellites from manufacturers with higher experience. De la Vega (2016) provides a list of 35 satellites (of more than 100 kg) that have been owned by Latin American organizations from 2000 to 2016. Of those, 27 satellites have been procured. Table 1.1 illustrates the main characteristics of those procurements.

Table 1.1 - List of satellites procured from 2000 to 2016 in Latin America.

Country	Satellite name	Type	Owner	Type of owner	Manufacturer	Year
Brazil	Brazilsat B4	Communications	Embratel	Private	Boeing (USA)	2000
Brazil	Hispasat 84W-1	Communications	Hispasat/Hispamar	Private	Thales Alenia Space (France/Italy)	2000
Brazil	Hispasat 30W-4	Communicaitons	Embratel	Private	Alcatel (France)	2002
Brazil	Telstar 14 (Estrela do Sul 1)	Communications	Telesat Brasil	Private	SSL (USA)	2004
Brazil	Amazonas 1	Communications	Hispasat/Hispamar	Private	EADS-Astrium (France)	2004
Brazil	Star One C12	Communications	Embratel	Private	Thales Alenia Space (France/Italy)	2005
Mexico	SATMEX-6 (EUTELSAT 113 West A)	Communications	EUTELSAT Americas	Private	SSL (USA)	2006
Brazil	Star One C1	Communications	Embratel	Private	Thales Alenia Space (France/Italy)	2007
Brazil	Star One C2	Communications	Embratel	Private	Thales Alenia Space (France/Italy)	2008
Venezuela	VENESAT-1 (Simón Bolivar)	Communications	ABAE	Public	CGWIC	2008
Brazil	Amazonas 2	Communications	Hispasat/Hispamar	Private	EADS Astrium (France)	2009
Brazil	Hispasat 30W-5	Communications	Hispasat/Hispamar	Private	SSL (USA)	2010
Brazil	Telstar 14R (Estrela do Sul 2)	Communications	Telesat Brasil	Private	SSL (USA)	2011
Chile	SSOT (FASAT-Charlie)	Earth observation	Chile Air Force	Public	EADS Astrium (France)	2011
Mexico	QuetzSat-1	Communications	QuetzSat	Private	SSL (USA)	2011
Brazil	Star One C3	Communications	Embratel	Private	Orbital Sciences Corp. (USA)	2012
Mexico	Mexsat-3 (Bicentenario)	Communications	MEXSAT	Public	Orbital Sciences Corp. (USA)	2012
Venezuela	VRSS-1 (Miranda)	Earth observation	ABAE	Public	CWIC	2012
Brazil	Amazonas 3	Communications	Hispasat/Hispamar	Private	SSL (USA)	2013
Bolivia	TKSAT-1 (Túpac Katari)	Communications	Bolivian Space Agency	Public	GWIC (China)	2013
Mexico	SATMEX-8 (EUTELSAT 117 West A)	Communications	EUTELSAT Americas	Private	SSL (USA)	2013
Brazil	Amazonas 4	Communications	Hispasat/Hispamar	Private	Orbital Sciences Corp. (USA)	2014
Brazil	Star One C4	Communications	Embratel	Private	SSL (USA)	2015
Mexico	SATMEX-7 (EUTELSAT 115 West B)	Communications	EUTELSAT Americas	Private	Boeing (USA)	2015
Mexico	Mexsat-1	Communications	MEXSAT	Public	Boeing (USA)	2015
Mexico	Mexsat-2 (Morelos)	Communications	MEXSAT	Public	Boeing (USA)	2015
Mexico	SATMEX-9 (EUTELSAT 117 West B)	Communications	EUTELSAT Americas	Private	Boeing (USA)	2016

Source: Adapted from De la Vega (2016).

Other recent space projects involving the procurement of satellites that are not on the aforementioned list are the Peruvian PerúSAT-1 satellite procured by the

Peruvian government from Airbus and the Brazilian SGDC-1 satellite procured by Visiona (a public-private joint venture) from Thales Alenia Space. (AIRBUS DEFENCE & SPACE, 2015; THALES ALENIA SPACE, 2013)

Ley et al. (2009) explain that commercial space programs typically have a high cost-effectiveness of the product (e.g. a satellite) through its use and low risks for development and operations.

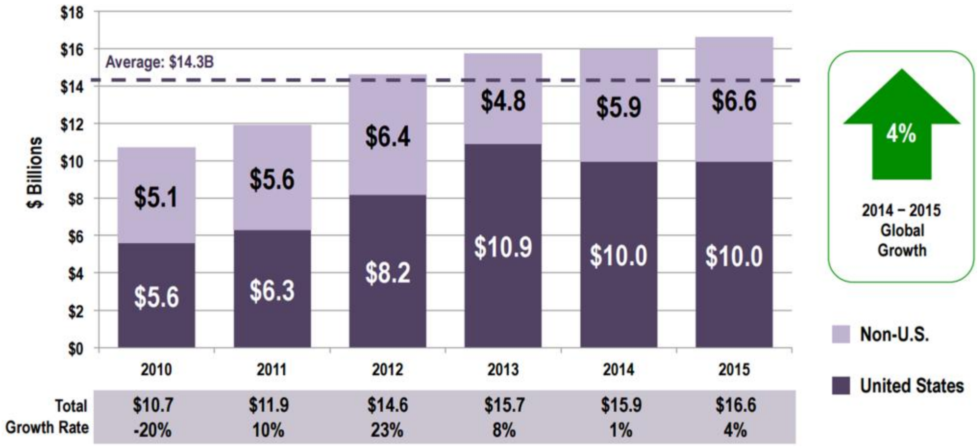
The previous facts show an opportunity to this work for supporting the lately and continuous increase of space projects in Latin America. Specifically, this work proposes a methodology that could be used to lead those efforts of developing space missions based on commercial satellites.

1.1.2 Satellites manufacturing market and turnkey satellites

Christensen et al. (2016) summarize the ‘2016 State of The Satellite Industry Report’, which is an annual study that is conducted by The Tauri Group for the Satellite Industry Association to provide objective measures of the satellite industry. This study involved a survey of over 80 companies, in-depth public information, and independent analysis to present indicators of the satellite industry in 2015 with respect to the previous 5 years.

Christensen et al. (2016) show that the satellite manufacturing segment of the satellite industry, which includes the construction and sale of satellites to both commercial and government customers, has been growing since 2010. Figure 1.1 illustrates such tendency in terms of the satellite manufacturing revenues.

Figure 1.1 - Global satellite manufacturing revenues (2010-2015).



Source: The Tauri Group (2016).

Furthermore, the author while doing a survey of satellites in the remote sensing market perceived that satellite manufacturers are currently offering several turnkey satellites. ‘Attachment A - catalog of remote sensing turnkey satellites’ shows a catalog of turnkey satellites offered on the market and their public specifications. Such turnkey satellites, which have predefined characteristics that could derive from previous designs, might provide the benefits that commercial products have provided to other industries. As the Academy of Aerospace Quality [S.d.] describes for commercial items, they provide benefits such as reduced costs, shorter development cycles, and reduced risks.

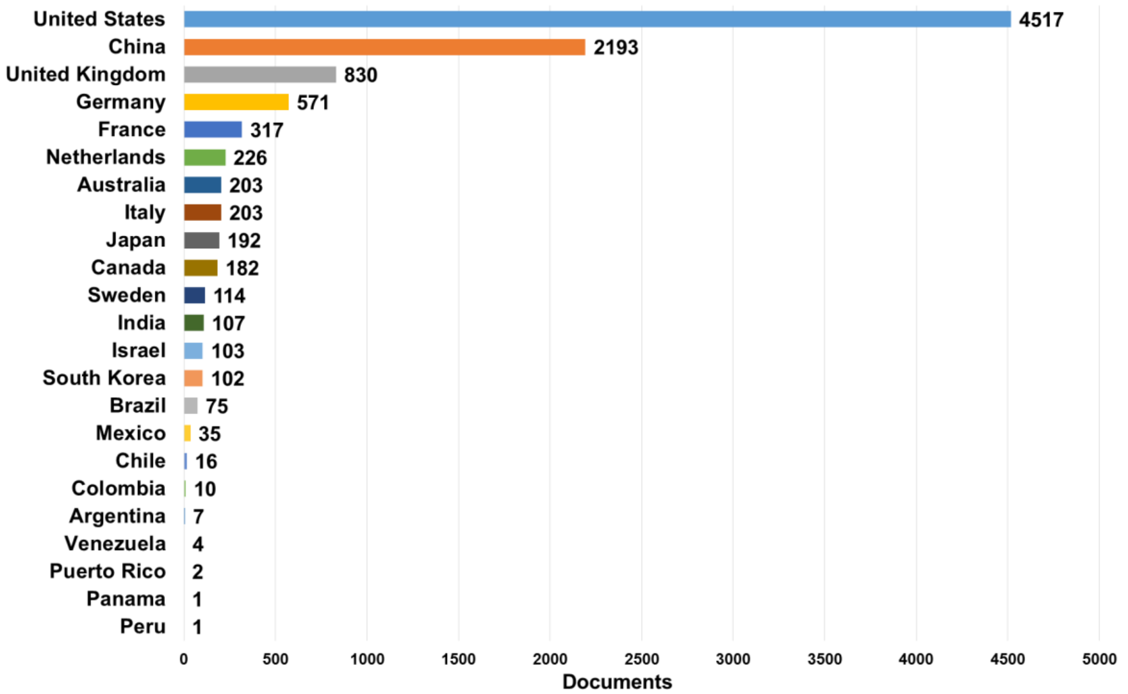
The previous facts show an opportunity to this work not only for supporting the increase of the number of space projects in Latin America by the procurement of commercial satellites but also for proposing the procurement specifically of turnkey satellites, and thus, taking advantage of their potential benefits.

1.1.3 **Systems engineering in Latin America**

Systems engineering is an approach for transforming a set of needs and constraints into a solution and supporting that solution throughout its life. The solution that the systems engineering effort produces is balanced, and thus, it considers the impact of its individual constituting elements and the aspects related to all the system lifecycle. Then, the solution that the systems engineering effort conceives satisfies in a near optimal matter the full range of intentions for the system. (DEFENSE SYSTEMS MANAGEMENT COLLEGE, 1990; EISNER, 2002; ISO et al., 2015a; LOUREIRO, 2015).

Systems engineering is not widely practiced in Latin American countries. A brief survey of engineering publications employing the term 'systems engineering' in their title or abstract suggests that besides Brazil and Mexico other Latin American countries have a low application of systems engineering. Figure 1.2 illustrates the number of publications related to systems engineering from 1948 to March 2017 according to Scopus bibliographic database in Latin American countries and other selected countries.

Figure 1.2 - Publications about 'systems engineering' by country from 1948 to 2017.



This chart includes the 15 countries with the highest number of publications and the Latin American countries with at least one publication related to 'systems engineering'. The chart illustrates that the application of systems engineering is low in Latin American countries when compared with respect to more developed countries.

Source: Adapted from Elsevier (2016).

Furthermore, it should be highlighted that it is common to refer to systems engineering in Latin American countries to the discipline that studies the computational systems (e.g. informatics, computer engineering, and software systems) and not to the discipline that study general man-made systems created and utilized to provide products or services in defined environments for the benefit of stakeholders.

The previous facts show an opportunity to this work for promoting the use of systems engineering in Latin America in the way that is performed in more developed countries. Specifically, this work proposes a systems engineering methodology that could not only lead a systems engineering effort but also could result in a balanced space system capable of fulfilling a particular set of needs even when such space system is to be based on turnkey satellites.

1.1.4 Traditional space systems engineering

Traditional space systems engineering is a top-down approach in which the design starts at the space system-level and proceeds onward to lower elements (e.g. satellites), the subsystems of the elements (e.g. power supply, communications, propulsion), the equipment of the subsystems (e.g. battery, reaction wheels, antenna), down to the level of parts (e.g. circuits, screws, cables). (LEY et al., 2009)

Bibliographic references on traditional space systems engineering methodologies do not make explicit how the systems engineering effort would change when considering the procurement of major elements (such as satellites). However, Sorensen and Road (2004) and Long and Road (2000) affirm that the use of commercial products does impact the traditional systems engineering effort, and consequently a particular approach is required in order to avoid risks. Saunders (2013) adds that many of the systems engineering practices and standards are perceived as being biased towards new development systems but the need to deliver quicker and cheaper solutions have translated into the higher reliance on the use of commercial products.

For that reason, he describes that the traditional top-down systems engineering effort should change to take into account the constraints that commercial products impose on the solution space in terms of functions, performance and interfaces. Other researches, mainly in the software industry have studied the impact and developed some particular approaches for accommodating the procurement of commercial products within the traditional development and systems engineering efforts. Section ‘2.3 Systems engineering with the use of commercial products’ contains detailed information about the researches related to this topic.

The aforementioned facts open an opportunity to this work to make explicit how the traditional space systems engineering approach would change when considering the procurement of satellites (specifically, turnkey satellites). Furthermore, such facts give an opportunity to this work to bring to the space industry some of the discoveries that other industries have already identified about the use of already available products.

1.2 Objectives

1.2.1 General objective

The main objective of this work is to propose a methodology for space systems engineering based on the procurement of turnkey satellites.

Traditional space systems engineering approach is used for the development of space systems conceived for a particular mission. Then, the methodology herein proposed targets to adapt such traditional approach for translating a set of customer and other stakeholders’ needs into a space system solution while accommodating the use of turnkey satellites.

1.2.2 **Specific objectives**

The specific objectives of the work are:

- Develop the methodology based on traditional space systems engineering methodologies and particular considerations for taking into account the concerns associated to the procurement of turnkey satellites;
- Apply the methodology to an application case for illustrating how the methodology should be used and for producing data that enables the judgment of the appropriateness of its application;
- Assess the methodology and the application case for concluding about the appropriateness of the methodology for projects considering the procurement of turnkey satellites while showing the similarities and particularities of the proposed methodology in comparison with a traditional space systems engineering methodology.

1.3 **Research approach**

Silva and Menezes (2005) describe that exists several ways of classifying researches (e.g. from the point of view of its nature, from the point of view in which the problem is approached, and from the point of view of the research objectives). According to Silva and Menezes' (2005) researches classification, this work could be classified from the point of view of its nature as an applied research since it targeted to produce knowledge for a practical application and a specific problem. The problem was approached in a qualitative manner since it was founded on the interpretation and attribution of meanings rather than on the use of statistical techniques and methods. Finally, from the point of view of the research objectives, this work can be considered as exploratory since it aimed to provide greater understanding of a problem in order to make it explicit.

Specifically, the development of the work consisted in the following activities:

a) Bibliographic research from published material mainly in the following areas:

   - Traditional systems engineering and space systems engineering methodologies. Main references used were the European Cooperation for Space Standardization (ECSS) standards, the National Aeronautics and Space Administration (NASA) systems engineering handbook, the Space Mission Analysis and Design (SMAD) book, the Applied Space Systems Engineering (ASSE) book, the International Council on Systems Engineering (INCOSE) systems engineering handbook, and the International Organization for Standardization (ISO), International Electrotechnical Commission (IEC), and Institute of Electrical and Electronics Engineers (IEEE) standards;
   - Findings and existing researches on development and systems engineering efforts considering the procurement of commercial products. This review was first performed using the searching keywords ‘systems engineering’ together with any of the following words: ‘procurement’, ‘acquisition’, ‘buying’, ‘buy’, or ‘purchase’ in scientific citation services such as Web of Science, Scopus, and Google Scholar, which includes many popular databases, journals, and proceedings and journals such as IEEE Xplore, ScienceDirect, Scielo, American Institute of Aeronautics and Astronautics (AIAA) journal, and INCOSE’s Systems Engineering journal. The International Astronautical Congresses (IAC) papers archive system was also reviewed. Other related researches were found by searching the keywords ‘OTS’, ‘COTS’, ‘off-the-shelf’, ‘off the shelf’, ‘commercial off-the-shelf’, or ‘commercial off the shelf’, and either ‘systems engineering’, ‘acquisition’, ‘development’, or ‘procurement’.

The terms Off-The-Shelf (OTS) and Commercial Off-The-Shelf (COTS)[2] were used as keywords since both represent the same logic that this work intends to apply with turnkey satellites: use a product that already was developed or specified in order to reduce the time-to-deploy the system and the cost of deploying that system. These references and their findings are in section '2.3 Systems engineering with the use of commercial products'.

b) Analysis of traditional systems engineering and space systems engineering methodologies;
c) Development of the proposed space systems engineering methodology by synthesis of activities from several systems engineering and space systems engineering methodologies. This synthesis was performed considering the findings described in section '2.3 Systems engineering with the use of commercial products' and the features of several systems engineering methodologies as described in 'Attachment B - SPSYSE-TK methodology development'. The results of this activity are in chapter '3 SPSYSE-TK: the proposed methodology';
d) Implementation of the methodology to an application case. For this activity, the following tasks were performed:
    - Selection of a relevant and appropriate traditional systems engineering methodology to be used as a reference for comparing the developed methodology. The selected methodology was the ECSS methodology. Details about its selection are in chapter '4 Application case';

[2] OTS and COTS are mostly used for items, such as software, motherboards, optical equipment, sensors and batteries; however, it has been already used for referring to turnkey satellites. Several references use both terms interchangeably. (ECSS, 2010, 2012; GAVAGHAN, 1998; INCOSE, 1998; ISO, 2007)

- Definition of a mission statement to be used as input for the ECSS and the proposed methodology. Details about the defined mission are in section '4.1 Mission description';
- Application of the proposed methodology to the defined mission. Details about this application are in section '4.2 Application of SPSYSE-TK methodology';
- Application of the ECSS methodology to the defined mission. Details about this application are in 'Attachment C - application of ECSS methodology'.

e) Qualitative assessment of the outcomes of this work. For this activity, the following tasks were performed:
    - Assessment of the proposed methodology with respect to the characteristics that a systems engineering approach that considers the use of commercial products should have according to the findings and existing researches about this kind of approach. This assessment was performed to demonstrate that the proposed methodology relies on such findings. Details about this assessment are in section '5.1 SPSYSE-TK methodology vs. previous findings';
    - Assessment of the proposed methodology and the application case to highlight the similarities and differences of the proposed methodology with respect to a traditional space systems engineering methodology such as ECSS's. Details about this assessment are in section '5.2 SPSYSE-TK methodology vs. ECSS traditional methodology';

f) Conclusions about the work and the proposed methodology with respect to the fulfillment of the objectives, contributions, expected impacts, limitations, and potential future works. Details about these conclusions are in chapter '6 Conclusions'.

1.4 Document structure

This document is structured as follows:

- Chapter '1 Introduction' describes the motivation, objectives, research approach, and the structure of this work;
- Chapter '2 Literature review' describes essential concepts that are related to the relevant topics of this work and contextualizes this work in terms of previous researches;
- Chapter '3 SPSYSE-TK: the proposed methodology' presents the main contribution of this work, which is the methodology for space systems engineering based on the procurement of turnkey satellites;
- Chapter '4 Application case' illustrates the application of the proposed methodology and a traditional space systems engineering methodology (specifically, the ECSS methodology);
- Chapter '5 SPSYSE-TK methodology assessment' provides a qualitative assessment of the proposed methodology with respect to a traditional space systems engineering methodology (specifically, the ECSS methodology);
- Chapter '6 Conclusions' demonstrates the fulfillment of objectives of this work and highlights the contributions, expected impact, limitations, and potential future works related to this work.

2 LITERATURE REVIEW

This chapter presents some basic concepts and ideas in which subsequent chapters of this work rely on. Specifically, this chapter presents basic concepts on space systems and systems engineering and the findings of several researches on systems engineering and development efforts that considered the use of commercial products.

2.1 Space systems

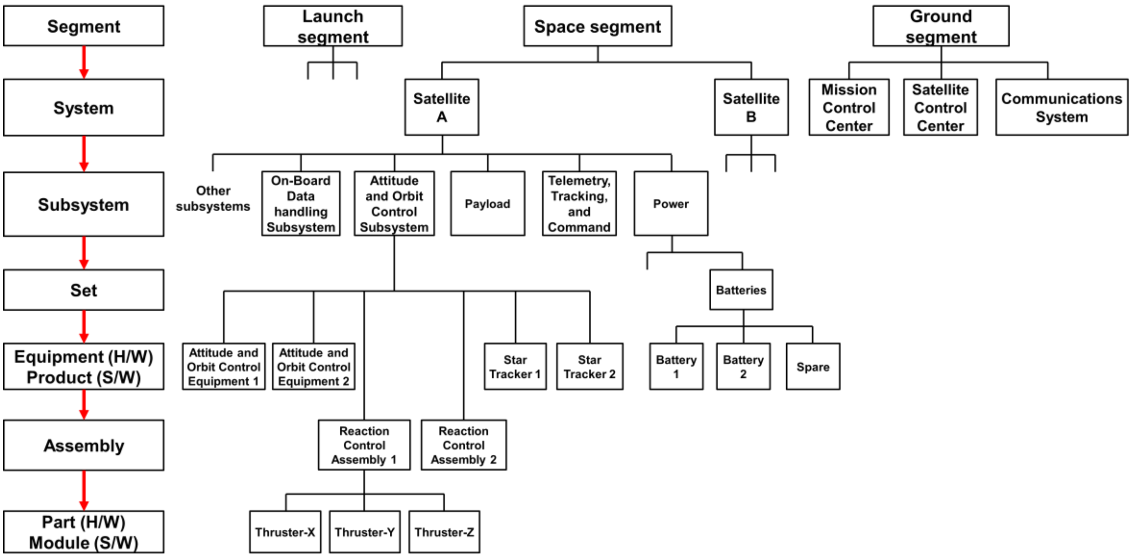
A space system is a complex unit of elements that interact to achieve a defined set of tasks, duties or functions, known as space mission (ECSS, 2012; LEY et al., 2009). A space system represents the highest-level system within a space project (ECSS, 2012).

ECSS (2012) states that a system shall contain at least a space, a ground, or a launch segment to be considered as a space system. However, space systems typically includes the three segments, which are coordinated according to the space mission objectives (LEY et al., 2009).

Segments are groupings of space system elements that fulfill a major subset of the space mission objectives. Segments examples are the space segment, the ground segment, the launch segment and the support segment. The space segment includes elements placed in space (e.g. spacecraft, satellite, payload, and platform). The ground segment includes elements located on ground (e.g. payload control center, spacecraft control center, ground station, ground station network, and ground communications network). The launch segment includes elements used for space segment element(s) transportation into space (e.g. launch vehicle and launch site facilities). Finally, the support segment includes elements used to support the development and operation of other elements (e.g. generic infrastructure and services, orbit computing facilities, test centers, briefing rooms, and training centers). (ECSS, 2012)

Figure 2.1 shows an example of the space system hierarchy within a space system.

Figure 2.1 - Example of a space system hierarchy.



In the left side, the figure illustrates the names of the hierarchical levels. In the right side, the figure illustrates an example of a space system decomposition.

Source: Adapted from Scholz (2017) and ECSS (2009b).

2.2 **Systems engineering**

ISO et al. (2015a, p.10) define systems engineering as the

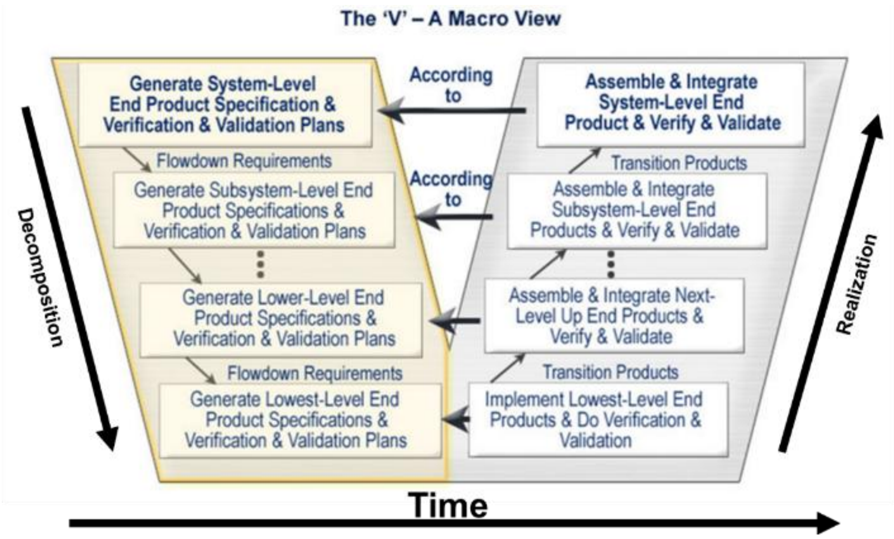
> Interdisciplinary approach governing the total technical and managerial effort required to transform a set of stakeholder needs, expectations, and constraints into a solution and to support that solution throughout its life. (ISO et al., 2015a, p.10)

INCOSE (2015) adds that systems engineering focuses on defining needs and required functionality early in the development cycle, documenting requirements, and performing the design synthesis and system validation while considering the complete problem (operations, cost and schedule, performance, training and support, manufacturing, and disposal). The United States Department of Defense (DOD) (2001) complements that systems engineering not only transforms needs and requirements into a product but also generates information for decision makers and provides input for next levels of development (adding value and more detail with each level).

DOD (2001) describes other important characteristics of systems engineering: it is a top-down, comprehensive, iterative and recursive effort. Mar (1997) adds that most systems engineering efforts are based on the hierarchical decomposition of the system into its parts. These characteristics help to describe the chronology of the systems engineering effort as beginning at the highest hierarchical level and going down to lower levels by adding value and more detail with the execution of the processes and the passage of iterations and recursions.

Figure 2.2 shows the Vee model, which provides a graphical representation of the decomposition of hierarchical levels through the time as described previously. The Vee model exhibits that systems engineering effort starts from the highest level (i.e. the system being the object of the systems engineering effort) and flows down to lower levels that appear by decomposition. Later, the lower levels are integrated and verified to realize higher levels. This logic continues up to the point where the highest level is realized.

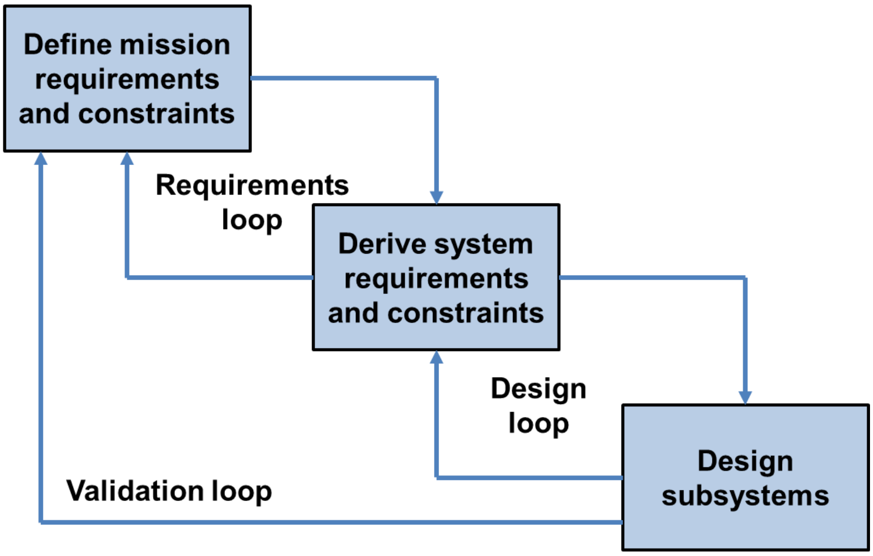
Figure 2.2 - The Vee model of systems engineering.



Source: Adapted from Prosnik (2010) cited by the BKCASE (2016) and from Forsberg et al. (2005) cited by the INCOSE (2015).

In the context of space systems, the systems engineering effort follows the logic that was previously described. It begins defining the space mission, which as described by ECSS (2012) represents a defined set of tasks, duties, or functions that the space system must achieve. Then, the systems engineering effort, which aims to develop a space system that meets the mission objectives, begins to flow down requirements to lower levels, such as the segments-level (e.g. space segment), then to the segment systems-level (e.g. satellite), and so on up to the lowest level within the development effort. The lowest level would depend on project considerations. Finally, the systems engineering effort leads the realization of the system through a bottom-up approach until the highest-level system is realized (i.e. the space system). Figure 2.3 illustrates this logic.

Figure 2.3 - Space systems engineering effort.



Source: Adapted from Jon Sellers et al. (2004).

‘Attachment D - systems engineering fundamentals’ provides further details about the systems engineering effort.

2.3 Systems engineering with the use of commercial products

This section describes findings of several researches on systems engineering and development efforts that considered the use of commercial products.

Findings are described in a chronology sequence and they are mainly from the software industry, which shows approximately 20 years of experience of using commercial products for developing software systems. Many of the researches used the terms Commercial Off-The-Shelf (COTS) and Off-The-Shelf (OTS) for referring to commercial products. As several references do, this work considers OTS and COTS as synonyms. Nevertheless, for describing researches, this work kept the term used originally by their authors.

In 1995, in a software industry symposium, Barry Boehm pointed that the use of COTS software was changing the development approach. While in the traditional approach system requirements were driving capabilities, in the COTS-based approach capabilities would drive system requirements. (BROWN et al., 1995)

Brownsword et al. (1998) stated that for a COTS-based system, requirements must be sufficiently flexible to accommodate a variety of available commercial products. They also stated that a critical relationship exists among technology and product selection, requirements specification, and architecture definition; then, these three essential elements must be worked in parallel with constant trade-offs among them. Brownsword et al. (1998) also added that the use of commercial products involves knowing policies, regulations, and directives regarding their use.

Long (2000) stated that incorporating an existing component into a system translates into savings in schedule and development costs. He also stated that using an existing component affects the systems engineering effort. He added that since COTS elements already exist, they were probably built to satisfy a set of requirements that may vary from those that are needed. Long (2000) also positioned the COTS elements into the architecture/synthesis process of the systems engineering effort, where the physical architecture of the system must be defined.

Brownsword et al. (2000) described that the traditional custom-development approach starts with the requirements identification, then it follows the architecture and design definition, and finally, it ends with the implementation of a system that meets the requirements. On the other hand, they described that COTS-based system development approach should start with a general set of requirements and then should explore what is available on the market to see how closely they match the needs. Brownsword et al. (2000) reaffirmed that the requirements, the architecture, and the market must be considered simultaneously and with recurring trade-offs among them.

Brownsword et al. (2000) also stated that often the differences between the traditional development approach and the COTS-based approach are not in which activities are done, but rather in how, when, or with what market considerations the activities occur. They exemplified that even when traditional approach includes trade-offs between requirements and architecture, the market considerations change the balance and nature of some of those trade-offs.

Mckinney (2001) stated that changes are needed in the systems engineering approach to the requirements analysis and design processes to take full advantage of available technology and products. He, in a software systems engineering context, also described that the conventional system development follows a sequence consisting in need identification, needs analysis, system requirements definition, functional allocation, derivation of software requirements, and finally, selection of applicable existing/COTS software. Then, he suggested that the effective use of COTS software requires performing the COTS assessment during the needs analysis process since the COTS products drive many system requirements definition specifications, dictate functional allocation, and determine some derived requirements.

Morisio et al. (2002), in a software context, proposed an approach for developing systems composed both by COTS elements and by customized elements. In that approach, Morisio et al. (2002) propose four main phases: requirements, design, coding, and integration. During the requirements phase, they suggest to perform together the requirements analysis and the COTS selection. They also recommend iterating between requirements and COTS selection until the number of candidates is reduced to two or three, which should be deeply evaluated. During the design phase, they suggest analyzing how to integrate COTS elements with the others by defining their interfaces and integration requirements. For the last two phases, they propose developing the interfaces and integrating the elements.

Albert and Brownsword (2002) stated that traditional approaches, involving definition of requirements, formulation of an architecture, and then a search for components that meet the specified requirements within the defined architecture, had been disappointing for the use of COTS and other pre-existing components. Consequently, they proposed the Evolutionary Process for Integrating COTS-based systems (EPIC). EPIC combines acquisition, management, and engineering practices for the use of those components through a simultaneous definition and trade-offs approach among the following four areas:

- Stakeholder needs – It consists in requirements (such as performance, or reliability), business drivers, or operational environments;
- Market – It consists in the available technology and products;
- Architecture/design – It consists in the essential elements (e.g. structure, behavior, usage, functionality, performance, and constraints) of the system and the relationships between them;
- Programmatics – It consists in management aspects of the project, such as cost, schedule, and risk.

Albert and Brownsword (2002) also suggested the use of four phases (i.e. inception, elaboration, construction, and transition) where the four areas will be converging into a solution. Péraire and Pannonne (2005) described the four phases of EPIC as follows:

- Inception phase – It consists in activities such as establishing project's scope, boundaries and acceptance criteria; identifying stakeholder needs; discriminating use cases and non-functional requirements; determining architectural and design constraints imposed on the solution by the COTS; estimating the project management constraints (e.g. time, money, people); identifying what is available on the market; producing Requests For Information (RFIs) or Requests for Proposal (RFPs); defining candidate solutions and demonstrating their feasibility; and recommending a short list of feasible solutions for detailed examination;
- Elaboration – It consists in activities such as refining stakeholder needs, architectural and design constraints, and project management constraints; understanding of the COTS alternatives; and finally, selecting and refining one solution among the candidates that best meets the demands and constraints;
- Construction – It consists in producing the solution;
- Transition – It consists in deploying the solution to the users and providing necessary support.

Sorensen (2004) similarly stated that using traditional systems engineering practices to accommodate COTS components requires focusing early in the design process on those activities that allow identification of the constraints imposed by those components. He added that the COTS alternatives bound the solution space and that the use of COTS reflects in a tendency to bypass the requirements analysis process, which introduces risks to the solution such as failing to fulfill the needs or over-engineering the solution (thus, implying increased costs).

Sorensen (2004) described the systems engineering COTS-driven design as a design and integration effort, in which the design process is now constrained by a set of pre-existing components that may or may not be required by a specific design solution. He also described this effort as a combination of a top-down approach with a reverse engineering approach. Finally, he suggested the parallel performing of the traditional requirements process (capture and decomposition) with a reverse engineering of the candidate components. The latter consists in exploring the market, identifying candidate components, and finally, exploring those candidates to derive their functional behavior and interfaces.

Perrone (2004) described the typical software system development approach consisting in the following activities: collection and definition of requirements; identification of the architecture that satisfies the requirements; design of individual subsystems in detail in order to fit then within the architecture; coding, testing, and debugging modules to meet the specified requirements; and integration of the sets of modules and subsystems into the complete system. Then, he stated that for COTS-based systems the approach needs to be revised. Consequently, he proposed a list of features that COTS-based approaches should follow. Some of the features listed by Perrone (2004) were the following:

- COTS procurement activities should be performed together with other traditional requirements engineering activities;
- The requirements engineering process should be iterative for allowing a progressive reduction of candidate solutions;
- The approach should have a guidance and may use well-known techniques for performing requirements activities and selection activities among alternatives;
- The approach should consider the functional and non-functional requirements that affect the alternatives selection;

- The approach should use multi-criteria decision-making techniques such as card sorts, Analytic Hierarchy Process (AHP), or Weighted Scoring Method (WSM), or any kind of weighted metrics for assessing the product compliancy against functional and non-functional requirements;
- The approach should help to extract from the commercial product description the information needed to make a selection against the requirements;
- Requirements should be adapted and balanced against COTS features;
- The approach should distinct between requirements used to select COTS components and requirements not helping the selection;
- The approach should consider the adaptation costs for the COTS alternatives selection;
- The approach should involve stakeholders in the product evaluation.

Yang et al. (2005) presented a framework for using COTS components in the software context. The framework begins with the identification of the stakeholders' desired objectives, constraints and priorities and goes through activities such as assessing the COTS candidates. The framework considers concurrent activities and frequent go-backs where the objectives, constraints, and priorities may be redefined. Yang et al. (2005) also described that assessing activities include some tasks such as establishing evaluation requirements, performing initial filtering among candidates, and carrying out a detailed assessment. They suggested performing a market trend analysis for ensuring relevant, up-to-date assessment information. Additionally, they proposed the utilization of an output document presenting the major results, conclusions, and recommendations gathered from the COTS assessment.

Walden (2007) described the roles of the systems engineers in three scenarios: traditional systems engineering scenario, COTS-based systems engineering scenario, and System-of-Systems (SoS) systems engineering scenario.

In the first scenario, representing traditional systems engineering, Walden (2007) described that the systems engineering effort goes primarily through stakeholder interaction, requirements analysis, and architectural design, while shaping and influencing the system solution through specifications, top-down design, and bottoms-up integration and test.

In the second scenario, representing the use of COTS components, Walden (2007) describes the systems engineering effort as a top-down approach of requirements and design activities which are adjusted to account for the bottoms-up constraints imposed by the COTS. Consequently, the whole effort is performed through requirements modifications and negotiations, along with simultaneous system design, integration, and test. Walden (2007) stated also that the traditional systems engineering effort is typically altered to allow the simultaneous top-down and bottom-up activities. He also described that COTS components come with a unique set of features (some desired and some not) and that many times the allocation and derivation of requirements is not completely compatible with the COTS features.

In the third scenario, representing a SoS scenario, Walden (2007) described that systems are treated as black boxes, and that systems place constraints on the SoS in the same way that COTS components place constraints on a system.

Torchiano (2008) presented in a software context the main processes that a software engineering team must perform (i.e. procurement and implementation). He listed inside the procurement process some activities such as identification of COTS alternatives, evaluation, selection, negotiation (or contracting), and analysis.

Torchiano (2008) also stated the following findings:

- OTS-specific activities are added to traditional development processes for integrating OTS components;

- Formal selection procedures are seldom used for selecting OTS products;
- There is no specific phase within the development process for selecting OTS components. The selection during early phases and late phases has both benefits and challenges;
- Involving customers in OTS components decisions is rare and sometimes unfeasible since they often lack technical knowledge.

Wang et al. (2010) mapped the systems engineering processes to the life cycle phases when reusing several types of items. For items that are reused as black boxes, they listed activities only during the following phases: conceptualization; operation, testing & evaluation; and transition to operation. Wang et al. (2010) excluded systems engineering activities during the development phase and included system design activities only during the conceptualization phase.

Saunders (2013) stated that many of the systems engineering practices and standards are perceived as being biased towards new development systems. He also stated that the need to deliver quicker and cheaper a system solution have translated into the higher reliance on the use of OTS components. He described that the use of OTS change the traditional top-down systems engineering effort since those components constrains the solution space in terms of functions, performance, and interfaces. Finally, Saunders (2013) proposed tailoring the systems engineering effort by performing the following four concurrent and iterative activities before the system requirements definition:

- Architecture definition – It consists in activities for capturing and analyzing stakeholder needs, and for deriving an architecture that suits with the best balance between the needs and constraints;
- Technology/market studies – It consists in activities for assessing the available relevant technologies and industry products based on trade

surveys, responses to expressions of interest, and requests for quotation;

- Technical integrity assessment – It consists in activities for verifying the compliancy on requirements;
- Risk management – It consists in activities for measuring, monitoring, and reducing the risk of the system solution.

At last, Coronel et al. (2015) studied the ECSS standard on off-the-shelf items utilization in space systems. The approach of that standard commands to develop an anticipated design of a solution, and then selecting and assessing the available OTS items the one that suits better with that design. Then, Coronel et al. (2015) compared this approach with the traditional software development approach. They showed that due to the similarities between both approaches the disadvantages of the traditional software development approach can be extrapolated to the ECSS's (e.g. narrowing the solution space to a very few products that fit with the anticipated design and investing too much time prior to evaluating and selecting the OTS product). This work is included within this document as 'Attachment E - previous published work'.

The United States Space and Missile Systems Center (SMC) (2012), the United States Air Force (USAF) (2000), the Brazilian Defense Ministry Command of Aeronautics (2007), and DOD (2013, 2010) provide approaches and activities that can be used for translating needs into an item that can be procured. They include the use of RFIs and the analysis and trade-offs among alternatives as other researches described in this literature review stated that are needed in systems engineering efforts that consider the use of commercial products. However, the degree of freedom of the aforementioned approaches is completely open so they allow specifying requirements for very low levels of the space system hierarchy, such as subsystems, components, and parts. Consequently, they are more appropriate for the procurement of customized commercial products rather than pre-specified commercial products such as turnkey satellites. For this reason, such approaches are more similar to a traditional systems engineering approach rather than to a systems engineering approach that considers the use of available commercial products as described by other researches. Furthermore, the aforementioned approaches were specifically developed for military applications, so they involve very complex organizational structures that relate the armed forces, the congress, and other governmental organizations participating in the system development. Consequently, the aforementioned approaches would be hard to implement by the different Latin American systems engineering groups that this work targets to be applicable by.

The performed literature review did not show any research for space systems engineering considering the procurement of turnkey satellites.

3 SPSYSE-TK: THE PROPOSED METHODOLOGY

This chapter describes the methodology that is proposed for developing space systems based on the procurement of turnkey satellites. First section describes its scope and second section describes the methodology.

3.1 Scope

This section presents the assumptions and limits in which the proposed methodology relies on.

3.1.1 Premises of the space project organizational structure

- The groups of experts or organizations participating in a space project are the stakeholders, systems engineering, management, engineering disciplines, product assurance, production, and the operations groups;
- The stakeholders groups includes a customer organization;
- The customer organization initially expresses having needs that it wants to address;
- The management group manages the project;
- The product assurance group ensures that space products accomplish their defined objectives in a safe, available, and reliable way;
- The production group includes the satellite manufacturing organization that performs the manufacturing, assembly, integration, and test of the space segment systems (i.e. satellites);
- The operations group is composed by an initial operations organization and a main operations organization. The initial operations organization deploys and commissions the space segment systems (i.e. satellites) while the main operations organization operates, supports, and disposes the space system elements;
- The systems engineering group defines the space system with support of the engineering disciplines groups;

- The systems engineering group is responsible for the definition of the space mission and the space system as well as for the planning of the technical activities in the space project;
- The engineering disciplines groups support the definition of the space system providing specialized knowledge and solutions as required by the systems engineering group.

3.1.2 Premises of the space project

- The space system that is needed to meet the customer and other stakeholders needs is specifically a space system whose space segment will orbit the Earth (i.e. a satellite system);
- A space system is composed by segments. Specifically, a space segment and one or more ground segments (e.g. ground application segment, ground control segment);
- A segment is composed by segment systems. Specifically, the space segment is constituted by one or more satellites and the ground segments are composed by ground segments systems, such as ground stations, ground control centers, mission or payload control centers, and communication networks;
- The satellites will be procured from the market with little or no customized modifications (i.e. turnkey satellites);
- The procurement of the turnkey satellites includes their launch service and they are only delivered to the main operations organization after commissioning (i.e. when they are into routinely working condition in orbit);
- The ground segments can be developed, procured, or already exist. In the first two cases, the systems engineering group implementing the methodology should be responsible at maximum for the definition of such segments up to the segment systems level (e.g. ground stations, ground control center, mission operations center, communication networks).

Lower levels of their development should be responsibility of other engineering disciplines groups.

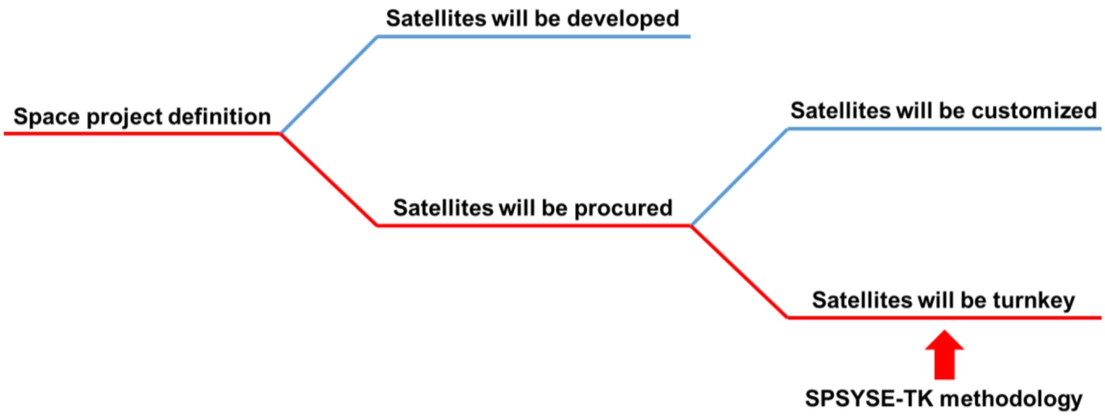
3.1.3 Premises of the proposed methodology

- The methodology is applied by the systems engineering group;
- The methodology begins with a mission statement provided by the customer organization indicating the needs that it wants to address;
- The methodology ends when a definition of the space system is complete, i.e. when it is available all the information relative to the space system (and its elements) necessary for its procurement, development, production, utilization, support, configuration management, and removal from service;
- The methodology covers the planning of activities (technical and programmatic) of the subsequent phases of the space project. However, the execution and control of such activities is assumed to happen after the definition of the space system, and thus, they are outside of the scope of the methodology;
- The methodology assumes that outputs from other groups that are necessary to enable its implementation are available when needed (e.g. management plans, procurement plans, product assurance plans, risk assessments, cost assessments, schedule assessments).

3.2 SPSYSE-TK methodology description

The methodology herein introduced covers the systems engineering effort that is required for defining space systems based on the procurement of turnkey satellites. Hereafter, the methodology will be referred as SPSYSE-TK methodology or simply as SPSYSE-TK. As described in chapter '1.2 Objectives', the SPSYSE-TK methodology herein introduced aims to translate an initial set of customer needs into a detailed definition of a space system that aims to fulfill such needs. The space systems within the scope of this work are those whose space segment is constituted by turnkey satellites. During the definition of a space project a decision can be made about if the satellites will be developed or procured (e.g. ‘make or buy’ decision). Then, a further decision can be made about if the satellites will be fully customized according to the needs that will be gathered or if the satellites will be turnkey (or ‘pre-specified’). In this last case, the SPSYSE-TK methodology will be applicable and it will allow taking advantages of the potential benefits of the turnkey satellites but taking risks on the non-fulfillment of some needs. Figure 3.1 illustrates this logic that should be considered before implementing the SPSYSE-TK methodology.

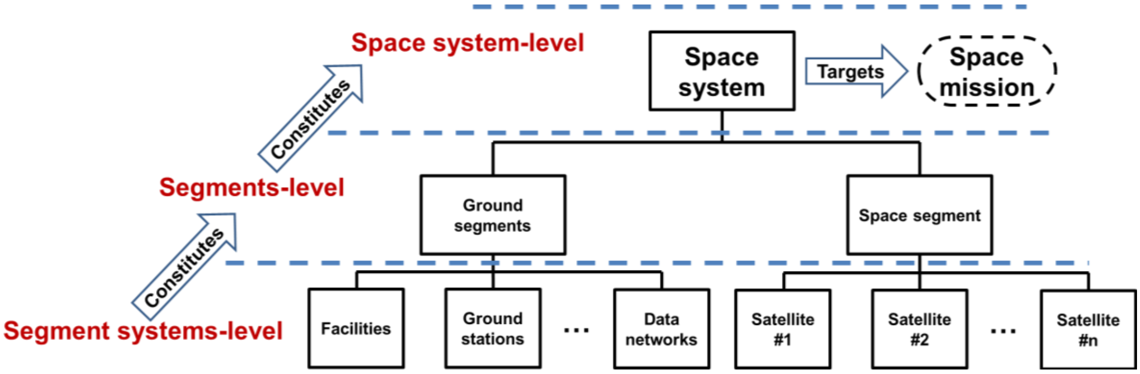
Figure 3.1 - Applicability of the SPSYSE-TK methodology.



Source: Author production.

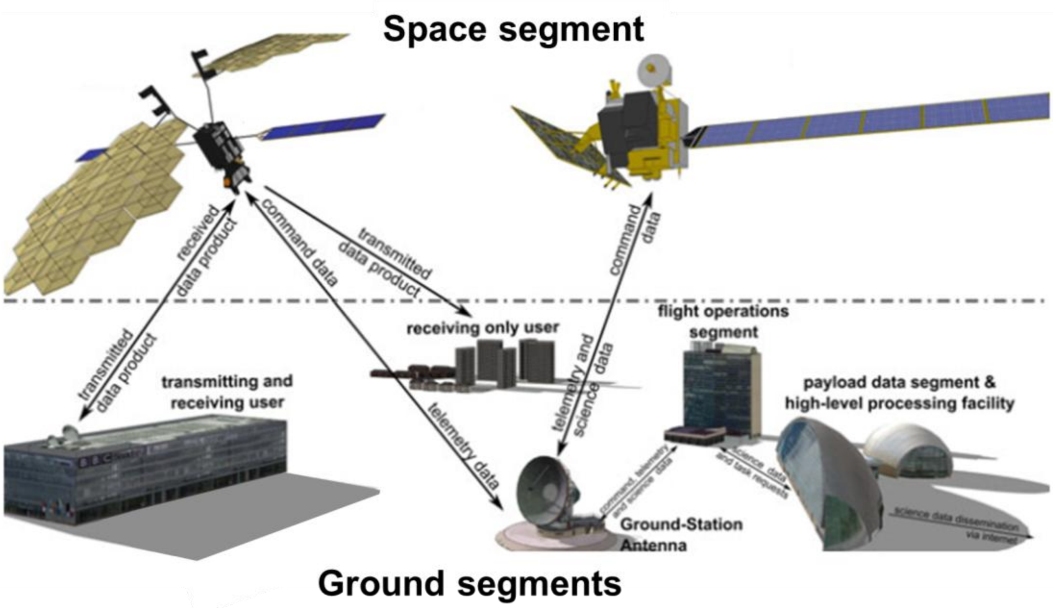
Figure 3.2 illustrates the space system hierarchy in which the SPSYSE-TK methodology relies on. The mission represents the goals that are intended to be met. The space system-level represents the space system that targets to achieve mission goals. The segments-level represents a partition of the space system. The segment systems-level is divided in a space segment and one or more ground segments. Finally, the segment systems-level represents a partition of the segments. The space segment is constituted by satellites while the ground segments can be constituted by elements such as facilities, ground stations, and data networks. Figure 3.3 illustrates an example of the aforementioned partitioning of the space system and its segments.

Figure 3.2 - Space mission hierarchy.



Source: Author production.

Figure 3.3 - Example of space segment and ground segments partitioning.



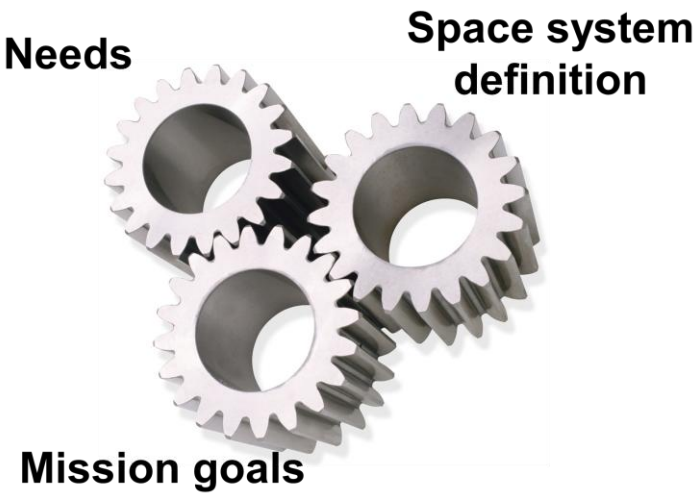
Source: Adapted from Macdonald and Badescu (2014).

Within the SPSYSE-TK methodology, the term ‘need’ refers to any thing that is wanted or required by a stakeholder. Needs can be related to functions, behaviors, or constraints, so they can be stated in either qualitative or quantitative terms. The term ‘constraint’ refers to any limitation that has been imposed by a stakeholder. Constraints can be related to aspects such as performance, cost, schedule, risk, interfaces, political goals, resources, existing systems, cooperation commitments, and policies. The term ‘programmatic aspects’ refers to non-technical constraints such as cost, schedule, and risk.

The term ‘requirements’ refers to matters that shall mandatorily be met. The term ‘conditional demands’ refers to matters that should preferably be met. Requirements and conditional demands can be associated with the mission (i.e. mission requirements and conditional demands) and the different hierarchical levels of the space system (e.g. space system requirements and conditional demands, segment system requirements and conditional demands). When referring to the space system or to the segment requirements and conditional demands, they include the requirements and conditional demands of the lower level elements. Finally, the term ‘mission goals’ comprises both mission requirements and mission conditional demands.

At the beginning, a set of needs starts the systems engineering effort. Such needs while being evolved and refined allow the definition of preliminary mission goals. Then, such mission goals allow the preliminary definition of a space system capable of meeting them. A refinement of the preliminary definition of the space system with respect to market-imposed characteristics allows the redefinition of the mission goals. Finally, such redefinition of the mission goals allow the redefinition of the space system. Figure 3.4 illustrates the aforementioned logic in which the methodology relies on.

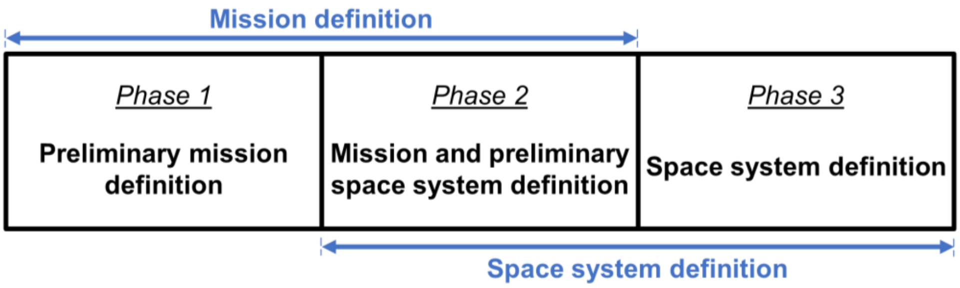
Figure 3.4 - SPSYSE-TK methodology logic.



Source: Author production.

The SPSYSE-TK methodology is divided in three phases. Through the first and second phases, the mission is defined (i.e. the issues that are required or desired to be solved are defined). Through the second and third phases, the space system that is expected to carry out the mission is defined taking into account market considerations regarding the space segment. Specifically, during the first phase, which is called 'preliminary mission definition' phase, the mission is preliminarily defined. During the second phase, which is called 'mission and preliminary space system definition', the mission is baselined and the space system is preliminarily defined in accordance with market imposed characteristics on the space segment. Finally, during the third phase, which is called 'space system definition' phase, the space system is defined in such a detail that the procurement, production, deployment, operation, support, and disposal of its elements can be performed in subsequent phases. Figure 3.5 illustrates the phases of the SPSYSE-TK methodology.

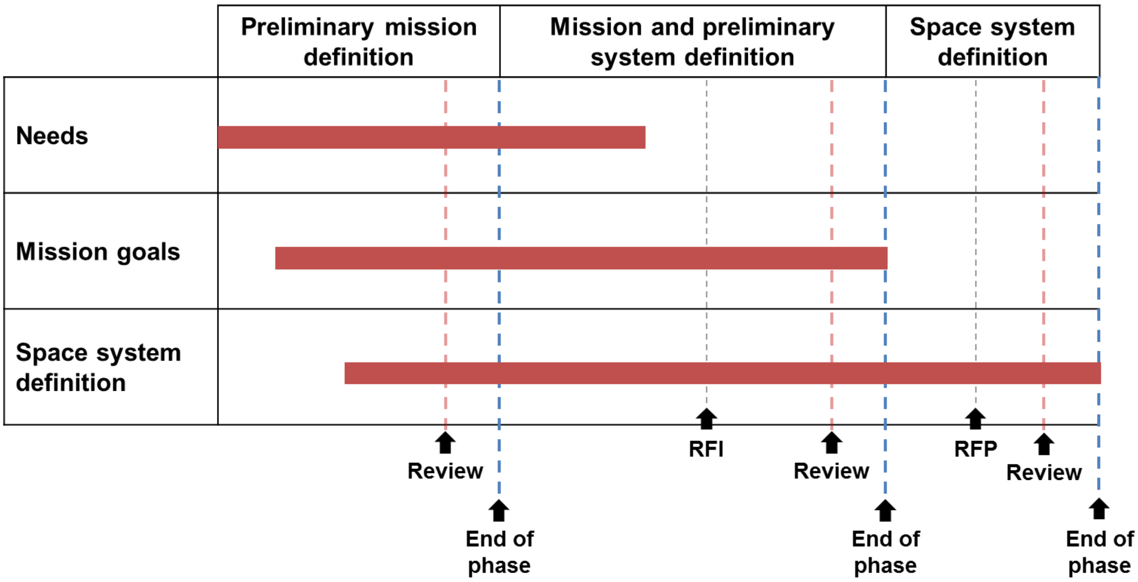
Figure 3.5 - Phases of the SPSYSE-TK methodology.



Source: Author production.

Figure 3.6 illustrates how the needs, mission goals, and the space system definition evolves along the phases. In accordance with ECSS standards (ECSS, 2009b), the space system definition is complete when it is available all the information relative to the space system (and its elements) necessary for its identification, manufacturing, utilization, support, configuration management, and removal from service. Examples of such information are lower level technical specifications, design and interface descriptions, drawings, electrical schematics, specified constraints (e.g. on materials, manufacturing, processes, and logistic).

Figure 3.6 - Evolution of needs, mission goals, and the space system definition.

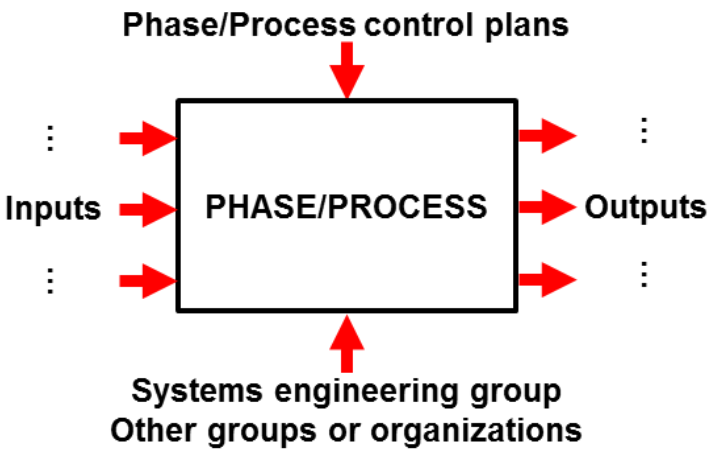


Source: Author production.

The following sections contain a description of each of the aforementioned phases. Specifically, following sections describe the objectives of the phase, the flowchart of processes and milestones that should be performed during the phase, and finally, the objectives and recommended activities within each of the processes and milestones. ‘Attachment B - SPSYSE-TK methodology development’ provides more details about how the methodology was developed and it highlights the main reference sources in which the methodology relies on.

In subsequent sections, phases and processes are described using IDEF0 representations. On the left and right sides, inputs and outputs are listed, respectively. On the top side, controls are listed. Due to the scope of this work, the controls are stated in a general form by the terms ‘phase control plans’ and ‘process control plans’ for phases and processes, respectively. It is done in such way since according to the Software Engineering Institute (2010), the project progress and performance is measured with respect to plans. A systems engineering group implementing the SPSYSE-TK methodology should choose the specific plans that it will use for controlling the phases and processes if it wants to ensure that the correct outputs are produced. Finally, on the bottom side, the mechanisms are listed. It should be noticed that the specification of the organization implementing the methodology is not within the scope of this work, and thus, the mechanisms described are the groups or organizations that are likely to participate in the phase or process. Furthermore, since the methodology herein proposed is to be applied by a systems engineering group, such group appears in all IDEF0 representations. Other groups or organizations that are listed indicate that they are likely to participate in the phase or process as required by the systems engineering group. Figure 3.7 illustrates the IDEF0 representations used.

Figure 3.7 - IDEF0 representations for phases and processes.



Source: Author production.

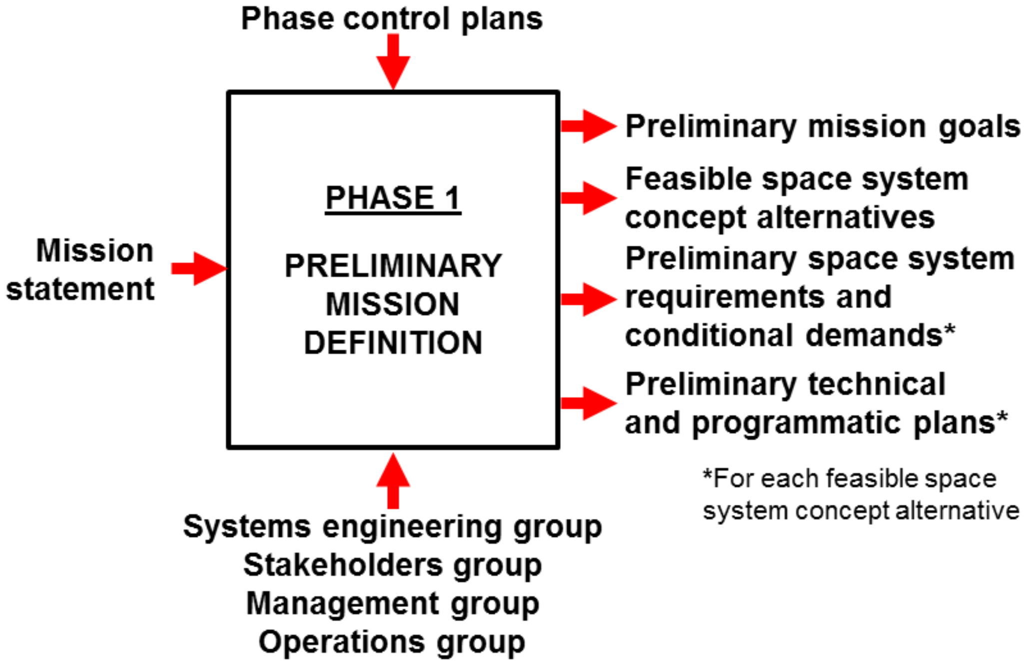
3.2.1 Phase 1: preliminary mission definition

3.2.1.1 Phase 1 objectives

The main objective of this phase is to define (in a preliminary way) the mission goals.

This phase begins with the input of a mission statement representing the initial needs of the customer. At the end of this phase, the systems engineering group should have produced a preliminary set of mission goals; some feasible operational concepts and architectures for the space system (i.e. space system concept alternatives); and a set of preliminary requirements, conditional demands, and plans for the feasible space system concept alternatives. Figure 3.8 illustrates the IDEF0 representation of this phase.

Figure 3.8 - Phase 1 IDEF0 representation.



Source: Author production.

The specific objectives of this phase within the systems engineering effort are:

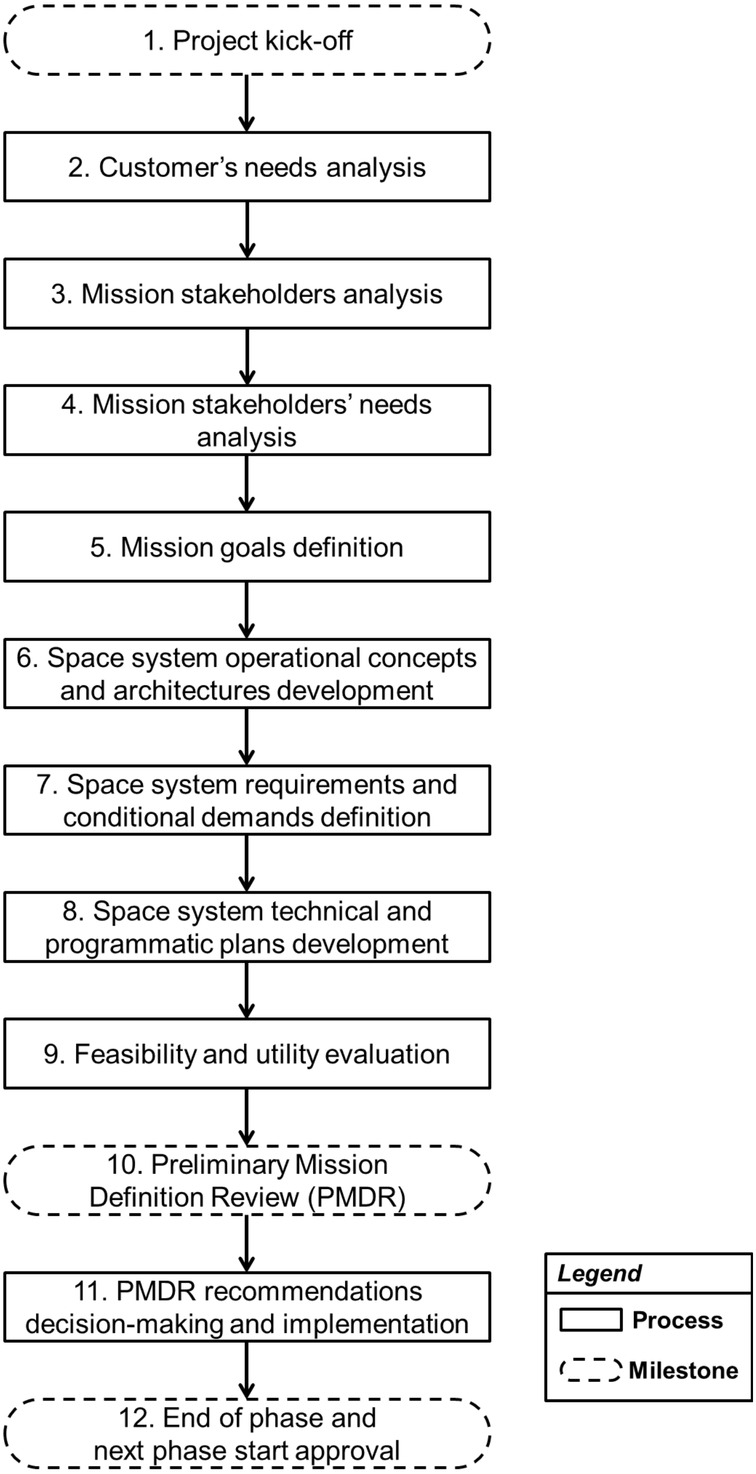
- Support the identification and refinement of the needs of the customer and other relevant mission stakeholders;
- Develop a set of preliminary mission goals (i.e. requirements and conditional demands);
- Propose operational concepts and architectures for the space system (i.e. space system concept alternatives);
- Develop preliminary requirements and conditional demands for each space system concept alternative as well as related technical and programmatic plans;
- Perform a preliminary assessment of the feasibility and utility of the space system concept alternatives.

During the current phase, main effort should be placed upon the processes that are related to the definition of mission goals. Processes related to the definition of the space system should be performed within this phase only to determine that the mission goals can be met and to have a preliminary idea of how well they would be fulfilled.

3.2.1.2 Phase 1 processes and milestones

Figure 3.9 shows a flowchart of the SPSYSE-TK methodology within this phase. Rectangle boxes indicate processes, while rounded boxes with dashed lines indicate milestones (e.g. reviews). Processes represent a series of tasks that the systems engineering should perform to transform an input into an output. Processes that are in parallel or in series can (and ideally, should) involve iterations between them. Milestones represent significant events during the development that should result in the review, confirmation, or authorization of the outcomes previously produced to advance to a subsequent process. The systems engineering group should participate in milestones; however, it should not be the responsible group of such events.

Figure 3.9 - Phase 1 of the SPSYSE-TK methodology.



Source: Author production.

Following subsections describe the objectives and the recommended activities for each process and milestone within this phase.

3.2.1.2.1 Project kick-off

This milestone represents the start of the space project. The kick-off should have the participation of the systems engineering group and the other groups and organizations participating in the project. The systems engineering group should be authorized to begin its effort as a result of this milestone.

The primary objectives of this milestone are:

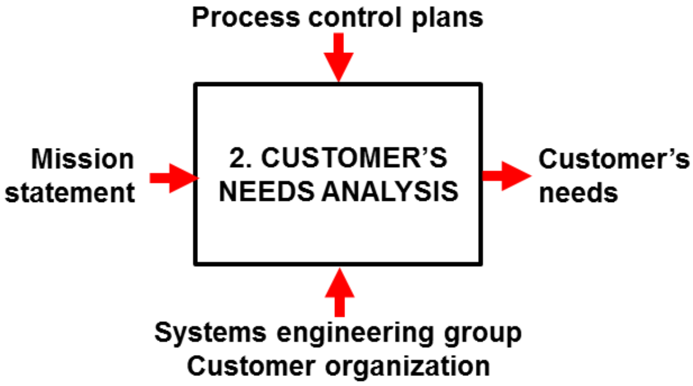
a. Define the necessary resources (e.g. money, time, staff, tools) and its allocation (e.g. roles, responsibilities) for the project; however, the main focus is on current phase;
b. Verify that all conditions for the initiation and execution of the project are agreed and met (including the resources availability);
c. Obtain written approval from higher-level authorities (e.g. project managers, customer) to begin the phase and use the allocated resources within the project.

3.2.1.2.2 Customer’s needs analysis

This process consists in analyzing and refining the needs declared by the customer in its mission statement.

This process begins with the input of a mission statement representing the initial needs of the customer. At the end of this process, the systems engineering group should have refined the customer’s needs in order to make them more detailed, unambiguous, and consistent. Unambiguous needs are those stated in a manner that can be only interpreted in one way. Consistent needs are those free of conflict with another need. Figure 3.10 illustrates the IDEF0 representation of this process.

Figure 3.10 - IDEF0 representation of the ‘customer's needs analysis’ process.



Source: Author production.

Specifically, this process should include the following tasks:

a. Review the customer’s mission statement to understand the needs (e.g. their drivers, their extent, and their context);
b. Identify implicit needs (e.g. based on domain knowledge, context understanding, and previously documented gaps);
c. Identify ambiguous or inconsistent needs;
d. Resolve ambiguous or inconsistent needs (together with the customer).

Needs can be gathered by many techniques such as questionnaires, interviews, workshops, operational observation, Quality Function Deployment (QFD), scenarios exploration, and brainstorming.

In this process, it is recommended to have several iterations with the customer to understand and refine the declared needs as well as new identified needs. It is also recommended to look for other potential needs that the customer might have not perceived or declared. Finally, it is recommended to involve the customer in the decision-making about ambiguous and inconsistent needs.

3.2.1.2.3 Mission stakeholders analysis

This process consists in defining the relevant stakeholders of the mission, i.e. those who will have more influence and the power to resolve issues related to the mission.

This process begins with the refined set of customer's needs. At the end of this process, the systems engineering group should have identified and ranked the relevant stakeholders that can influence the definition of the mission goals. Figure 3.11 illustrates the IDEF0 representation of this process.

Figure 3.11 - IDEF0 representation of the 'mission stakeholders analysis' process.

Source: Author production.

Specifically, this process should include the following tasks:

a. Identify new mission stakeholders besides the customer (e.g. users, sponsors, local government);
b. Define the relevant stakeholders for the mission (including the customer);
c. If possible, rank the relevant stakeholders.

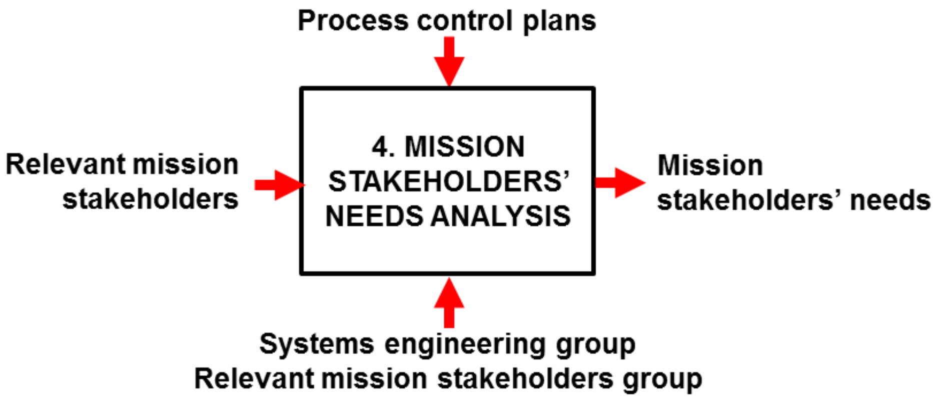
Mission stakeholders can be identified by different methods such as brainstorming or stakeholder influence maps.

3.2.1.2.4 Mission stakeholders’ needs analysis

This process consists in defining an unambiguous, consistent, and classified set of needs, which represent the needs of the relevant mission stakeholders.

This process begins with the list of relevant and ranked mission stakeholders. At the end of this process, the systems engineering group should have gathered and refined a set of mission stakeholders’ needs (including the previously identified customer’s needs) in order to make them more detailed, unambiguous, and consistent. Unambiguous needs are those stated in a manner that can be only interpreted in one way. Consistent needs are those free of conflict with another need. Figure 3.12 illustrates the IDEF0 representation of this process.

Figure 3.12 - IDEF0 representation of the ‘mission stakeholders' needs analysis’ process.



Source: Author production.

Specifically, this process should include the following tasks:

a. Elicit needs from the relevant mission stakeholders;
b. Review the mission stakeholders’ needs;
c. Identify implicit needs;
d. Identify ambiguous or inconsistent needs;
e. Resolve ambiguous or inconsistent needs (together with the relevant mission stakeholders);

f. Classify the needs into essential (i.e. those that shall be met), conditional (i.e. those that are desirable to be met), and optional (i.e. those that are not interesting to be met within current mission) (together with the relevant mission stakeholders);
g. Rank the conditional needs.

Tasks a. to c. do not include the customer's needs since they were gathered in a previous process. However, tasks c. to g. do include the customer's needs.

Needs can be gathered by many techniques such as questionnaires, interviews, workshops, operational observation, Quality Function Deployment (QFD), scenarios exploration, Systemic Textual Analysis (STA), and brainstorming.

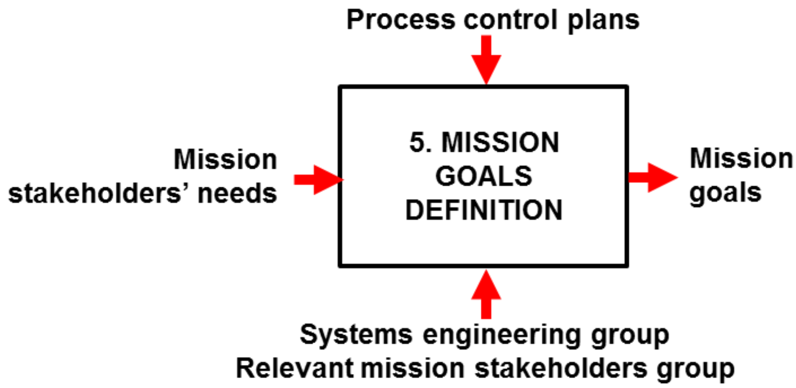
In this process, it is recommended to have several iterations with the mission stakeholders to understand and refine the declared needs as well as new identified needs. It is also recommended to look for other potential needs that the mission stakeholders might have not perceived or declared. Finally, it is recommended to involve the most relevant stakeholders in the decision-making about ambiguous and inconsistent needs as well as in the classification of the needs into essential, conditional, and optional.

3.2.1.2.5 Mission goals definition

This process consists in establishing the preliminary mission goals (i.e. mission requirements and mission conditional demands).

This process begins with the refined set of needs of the relevant mission stakeholders. At the end of this process, the systems engineering group should have produced a set of preliminary mission goals representing what the mission shall meet (i.e. mission requirements) and what the mission preferably should meet, if possible (i.e. conditional demands). Figure 3.13 illustrates the IDEF0 representation of this process.

Figure 3.13 - IDEF0 representation of the 'mission goals definition' process.



Source: Author production.

Specifically, this process should include the following tasks:

a. If not determined yet, define how the fulfillment of each essential need will be assessed (i.e. technical measures);
b. If not determined yet, define the minimum success criteria (based on the technical measures) to meet each essential need;
c. Establish the mission requirements as 'shall' statements from the essential needs, their technical measures, and their minimum success criteria;
d. If applicable and not determined yet, how the fulfillment of each conditional need will be assessed (i.e. technical measures);
e. If applicable and not determined yet, define the preferred values (based on the technical measures) for each conditional need;
f. Establish the conditional demands as 'should' statements from the conditional needs, their technical measures, and their preferred values.

In this process, it is recommended to establish technical measures and minimum success criteria for the essential needs (if not established previously by mission stakeholders). By doing this, the essential needs can be established as requirements representing the minimum features that the mission shall address. Anything better would be a plus, and consequently, it could be used as a criterion to choose among alternatives.

Conditional needs can be transformed into measurable or immeasurable conditional demands. Immeasurable conditional demands are those whose fulfillment at any degree would be valuable for the mission (e.g. having pointing capability); and consequently, they could be used as a criterion to choose among alternatives. Measurable conditional demands are those whose fulfillment only would be valuable from a certain level (e.g. having pointing capability of more than a given value). For measurable conditional demands, it is recommended to establish technical measures and desired values for the related conditional needs (if not established previously by mission stakeholders). In these cases, anything equal or better than the desired value could be used as a criterion to choose among alternatives. Anything below such value, it is assumed that would not add enough value to the mission to be used as a criterion to choose among alternatives.

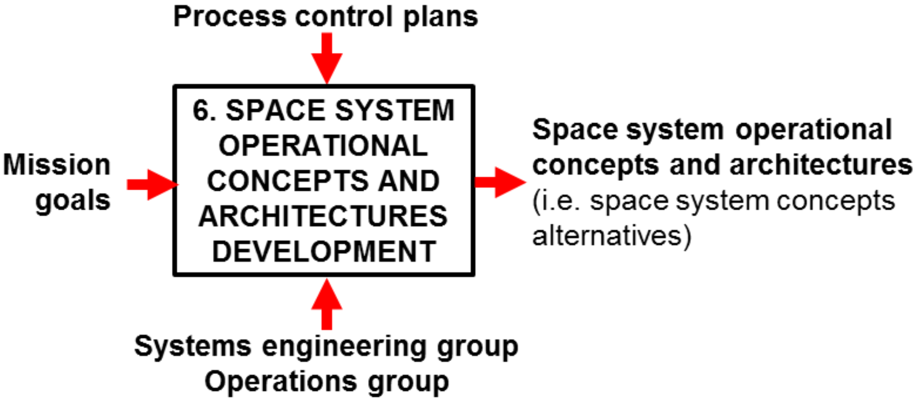
Examples of mission goals are subjects signatures, data product characteristics, functions, performance, coverage, launch date (or window), timeliness, geolocation accuracy, periodicity, cost, schedule, lifetime, reliability, availability, and latency.

3.2.1.2.6 Space system operational concepts and architectures development

This process consists in producing some preliminary representations of the major elements (i.e. segments and segments systems) that will constitute the space system and how such elements will operate to meet mission goals (mandatorily, the mission requirements, and if possible, the conditional demands).

This process begins with the preliminary defined mission goals. At the end of this process, the systems engineering group should have produced some space system operational concepts and architectures (i.e. space system concepts alternatives) that are expected to meet mission goals (mandatorily, the mission requirements, and if possible, the conditional demands). Figure 3.14 illustrates the IDEF0 representation of this process.

Figure 3.14 - IDEF0 representation of the 'space system operational concepts and architectures development' process.



Source: Author production.

Specifically, this process should include the following tasks:

a. Review the 'as-is' of the preliminary mission requirements and conditional demands (i.e. how those concerns are addressed or partially addressed currently) to identify matters that might affect, interact, or be part of the space system (e.g. existing systems and infrastructure; organizations, personnel, roles, and responsibilities; regulations, policies, and procedures; performance, cost, and schedule drivers; and data formats and communication protocols);
b. Define broadly the major elements (i.e. segments and segments systems) that will constitute the space system (e.g. satellites, ground stations, control centers);
c. Define the major elements that shall be specified within the current systems engineering effort;
d. Define representative operational scenarios (or use cases) that represent anticipated uses of the space system (e.g. what the elements will exchange and in which sequence they will do it, timelines);
e. If needed, refine the major elements definition according to the operational scenarios;
f. Repeat from b. to e. to define alternative operational concepts and architectures (i.e. space system concept alternatives).

It is recommended that this process does not output too many space system concept alternatives. Otherwise, the systems engineering effort could become too hard to manage.

Operational concepts and architectures can be characterized by several techniques, such as Work Breakdown Structure (WBS), N2 charts, sequence or activity charts, functional block diagrams, structure charts, allocation charts, data flow diagrams, object diagrams, and context diagrams.

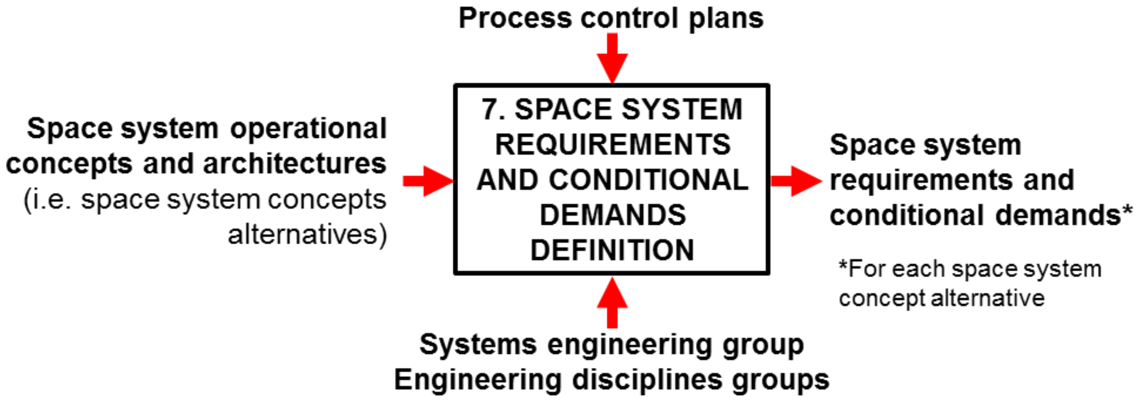
The space system concept alternatives (i.e. operational concepts and architectures) should describe in a high-level manner the major elements of the space system and operational features that are to be provided for them to fulfill mission goals, including aspects such as how the major elements will operate, how and when the major elements will interact and under which circumstances, relevant events, preliminary orbit, preliminary number of satellites, relevant subject features, modes, and timelines.

3.2.1.2.7 Space system requirements and conditional demands definition

This process consists in establishing the preliminary requirements and conditional demands for each space system concept alternative.

This process begins with the space system concept alternatives. At the end of this process, the systems engineering group should have produced a set of requirements and conditional demands for each space system operational concept and architecture (i.e. space system concepts alternative). Figure 3.15 illustrates the IDEF0 representation of this process.

Figure 3.15 - IDEF0 representation of the 'space system requirements definition' process.



Source: Author production.

Specifically, this process should include the following tasks:

a. Review the mission requirements and conditional demands to identify required and desired characteristics that the major elements of the space system (i.e. segments and segment systems) are expected to have or do;
b. Review the operational scenarios to identify required and desired characteristics that the major elements of the space system (i.e. segments and segment systems) are expected to have or do;
c. If not determined yet, define how the fulfillment of each required or desired characteristic will be assessed (i.e. technical measures);
d. If not determined yet, define the minimum success criteria (based on the technical measures) to meet each required characteristic;
e. Establish the space system requirements as 'shall' statements from the required characteristics, their technical measures, and their minimum success criteria;
f. If applicable and not determined yet, define the preferred values (based on the technical measures) for each desired characteristic;
g. Establish the space system conditional demands as 'should' statements from the desired characteristics, their technical measures, and their preferred values;
h. Repeat from a. to g. for each space system concept alternative.

Different techniques can be used for identifying and deriving required and desired characteristics, such as context analysis, functional analysis, context flow diagrams, states and modes analysis, state transition diagrams, rest of scenario analysis, and Entity-Relationship Attribute (ERA).

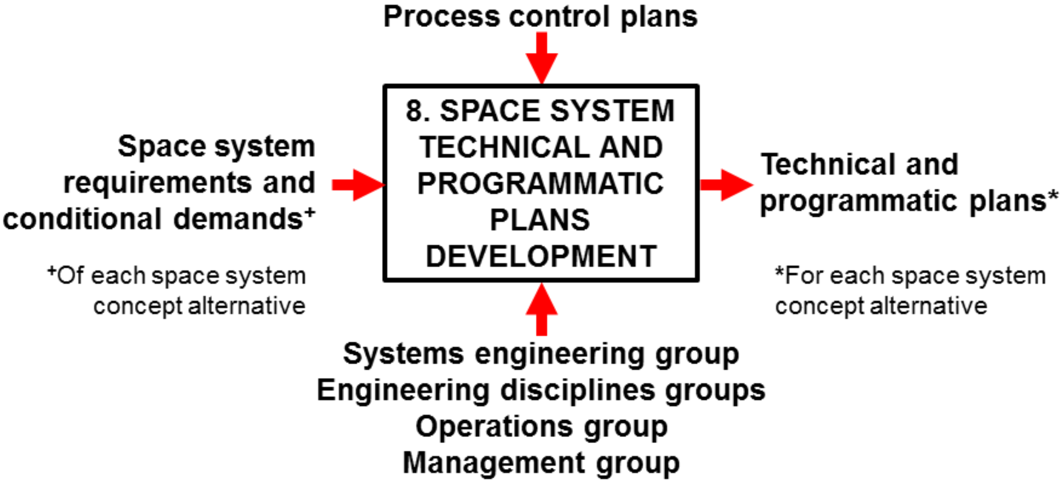
Examples of space system characteristics that can be either requirements or conditional demands are preliminary orbit; duty cycle; ground sample distance; revisit; channel numbers; channel bandwidth; transmission frequency; spectral resolution; data rate; pointing stability; pointing accuracy; slew rate; data rate; field of view; maintenance; data generation, processing, and storage capabilities; reliability; availability; cost; schedule; operational aspects (e.g. sequences, timelines); functions; states; modes; inputs; outputs; interfaces; performance; environment; quality; resources; data protocols; latency; data management; lifetime; and autonomy.

3.2.1.2.8 Space system technical and programmatic plans development

This process consists in establishing the preliminary plans that will lead the subsequent phases for each space system concept alternative (including programmatic aspects).

This process begins with the space system requirements and conditional demands of each space system concept alternative. At the end of this process, the systems engineering group should have produced a set of technical and programmatic plans for each space system concept alternative. Figure 3.16 illustrates the IDEF0 representation of this process.

Figure 3.16 - IDEF0 representation of the ‘space system technical and programmatic plans development’ process.



Source: Author production.

Specifically, this process should include the following tasks:

a. Define a systems engineering plan for the subsequent phases of a space system concept alternative, focusing on activities of the following phase (e.g. processes, analyses approaches, trade studies to be used; organizational roles and responsibilities);
b. Identify other technical and programmatic plans that shall be developed (e.g. mission operations plan, schedule plan, cost plan, RFI distribution plan);
c. Support the definition of the other plans for the subsequent phases, focusing on activities of the following phase;
d. Review the preliminary plans to estimate broadly the programmatic aspects of the space system concept alternative;
e. Repeat from a. to d. for each space system concept alternative.

Technical plans cover all the technical effort required to develop the space system and its elements, including their definition, integration, verification, validation, operations, and disposal. Technical plans can include technical reviews, audits, margin policies, assessments, and status reports, for instance. Example of technical plans are the systems engineering plan, configuration management plan, data management plan, engineering specialty plans (e.g. reliability plan and quality control plan), mission operations plan, verification plan, AIT plan, and the mission assurance plan. The systems engineering plan describes how the systems engineering effort will be managed and conducted along the lifecycle phases and can embrace other technical plans, such as the verification plan, requirements management plan, and the mission operations plan.

Alternatively, programmatic plans are related to aspects such as cost, schedule, and risk. Examples of programmatic plans are the risk management plan, cost plan, procurement plan, and the schedule plan.

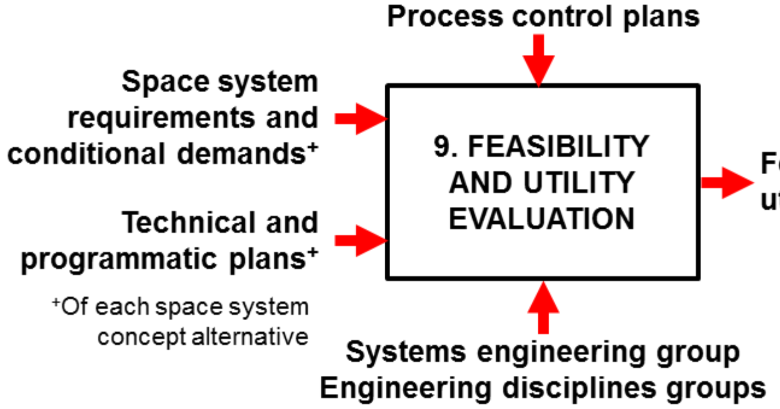
Both the technical and programmatic plans allow estimating the programmatic aspects such as work costs, schedules, risks, cooperation commitments, industrial policies, regulations and other needed resources (e.g. workforce, facilities, and equipment).

3.2.1.2.9 Feasibility and utility evaluation

This process consists in assessing the feasibility and utility of the different space system concept alternatives.

This process inputs the space system requirements and conditional demands as well as the plans of each space system concept alternative. At the end of this process, the systems engineering group should have produced a set of feasibility and utility results and a selection of some feasible space system concept alternatives that will advance to the next phase. Figure 3.17 illustrates the IDEF0 representation of this process.

Figure 3.17 - IDEF0 representation of the ‘feasibility and utility evaluation’ process.



Source: Author production.

Specifically, this process should include the following tasks:

a. Assess the technical feasibility of a space system concept alternative (i.e. if the alternative is achievable in terms of technical aspects);
b. Assess the programmatic feasibility of the space system concept alternative (i.e. if the alternative achievable in terms of programmatic aspects such as plans and project constraints);
c. Repeat a. and b. for each space system concept alternative;
d. Discard unfeasible (either technical or programmatic) alternatives;
e. Assess the mission utility of the feasible space system concept alternatives;
f. Select some space system concept alternatives with the highest utility values that will advance to the next phase.

Different techniques can be used for selecting among alternatives, such as multi-criteria decision-making, analytic hierarchy process (AHP), weighted scoring method (WSM), cost-versus-benefit studies. However, the SPSYSE-TK methodology encourages the selection of an alternative based on the utility that adds to the mission (i.e. mission utility). The mission utility represent a function of how much valuable an alternative can be according to any certain criteria, which is likely to depend mainly on conditional demands. Criteria should be defined together with the relevant mission stakeholders. Examples of criteria can be the improved fulfillment of mission requirements, higher number of fulfilled conditional demands, lowest risk, lowest cost, shorter delivery time, or the best fulfillment of a particular mission requirement or conditional demand.

3.2.1.2.10 Preliminary Mission Definition Review (PMDR)

This milestone represents a review of the most important outcomes that have been produced within this phase; specifically, the preliminary mission goals, the feasible space system concept alternatives (including their requirements, conditional demands, and plans), and the feasibility and utility results. This review should be performed by an external group of specialists with the appropriate knowledge and experience to judge the content that has been produced in this phase. The systems engineering group should participate in the review to provide clarifications, assess recommendations (together with the relevant mission stakeholders), and implement recommendations when required.

The primary objectives of this milestone are:

a. Assess the preliminary mission goals; the feasible space system concept alternatives, which include their requirements, conditional demands, and plans; and the feasibility and utility results;
b. Establish recommendations showing issues such as unidentified errors, incomplete information, unfeasible requirements, inaccurate plans, and potential actions;
c. If possible during the review, assess the implementation of some of the recommendations (together with the relevant mission stakeholders);
d. If possible during the review, implement some of the accepted recommendations.

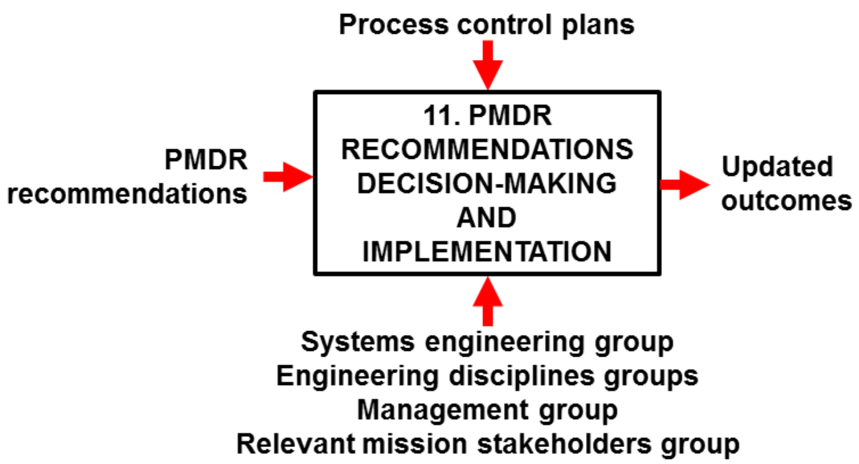
The idea of this review is to ensure that at least one space system concept alternative is feasible before proceeding to the next phase.

3.2.1.2.11 PMDR recommendations decision-making and implementation

This process consists in assessing and implementing some of the recommendations that were produced during the PMDR but were not assessed or implemented during such review.

This process inputs the recommendations of the PMDR. At the end of this process, the systems engineering group should have update the outcomes of this phase with the accepted recommendations of the PMDR. Figure 3.18 illustrates the IDEF0 representation of this process.

Figure 3.18 - IDEF0 representation of the 'PMDR recommendations decision-making and implementation' process.



Source: Author production.

Specifically, this process should include the following tasks:

a. Assess the implementation of the recommendations that were not assessed during the PMDR (together with the relevant mission stakeholders);
b. Implement the accepted recommendations that were not implemented during the PMDR or those that were accepted in a.

3.2.1.2.12 End of phase and next phase start approval

This milestone represents the end of the current phase and the start of the next phase. The outcomes of the current phase should be approved and released. Then, the systems engineering group should be authorized to begin the effort of the next phase as a result of this milestone.

The primary objectives of this milestone are:

a. Obtain written approval from higher-level authorities to close the current phase;
b. Release the outcomes of this phase;
c. Obtain written approval from higher-level authorities to begin the next phase and use the allocated resources during the following phase.

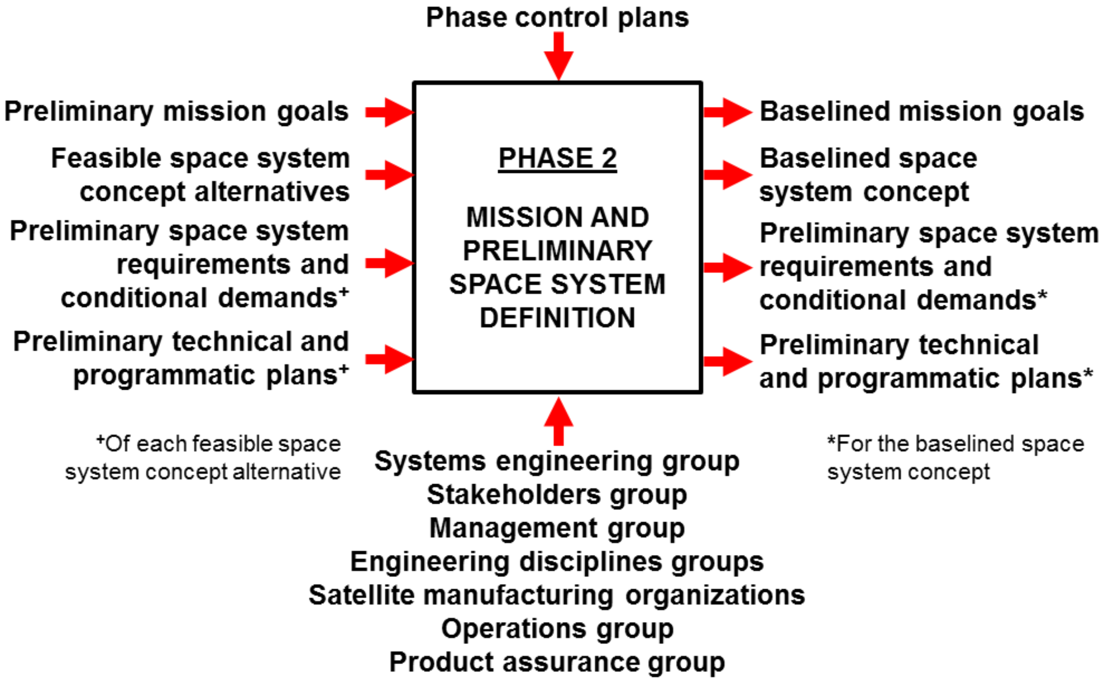
3.2.2 Phase 2: mission and preliminary space system definition

3.2.2.1 Phase 2 objectives

The main objective of this phase is to define (in a final way) the mission goals and to define (in a preliminary way) the space system that will meet such goals.

This phase begins with the reviewed and approved outputs of the previous phase. At the end of this phase, the systems engineering group should have produced a baselined set of mission goals; a baselined operational concept and architecture for the space system (i.e. space system concept); and a set of preliminary requirements, conditional demands, and plans for the baselined space system concept. Figure 3.19 illustrates the IDEF0 representation of this phase.

Figure 3.19 - Phase 2 IDEF0 representation.



Source: Author production.

The specific objectives of this phase within the systems engineering effort are:

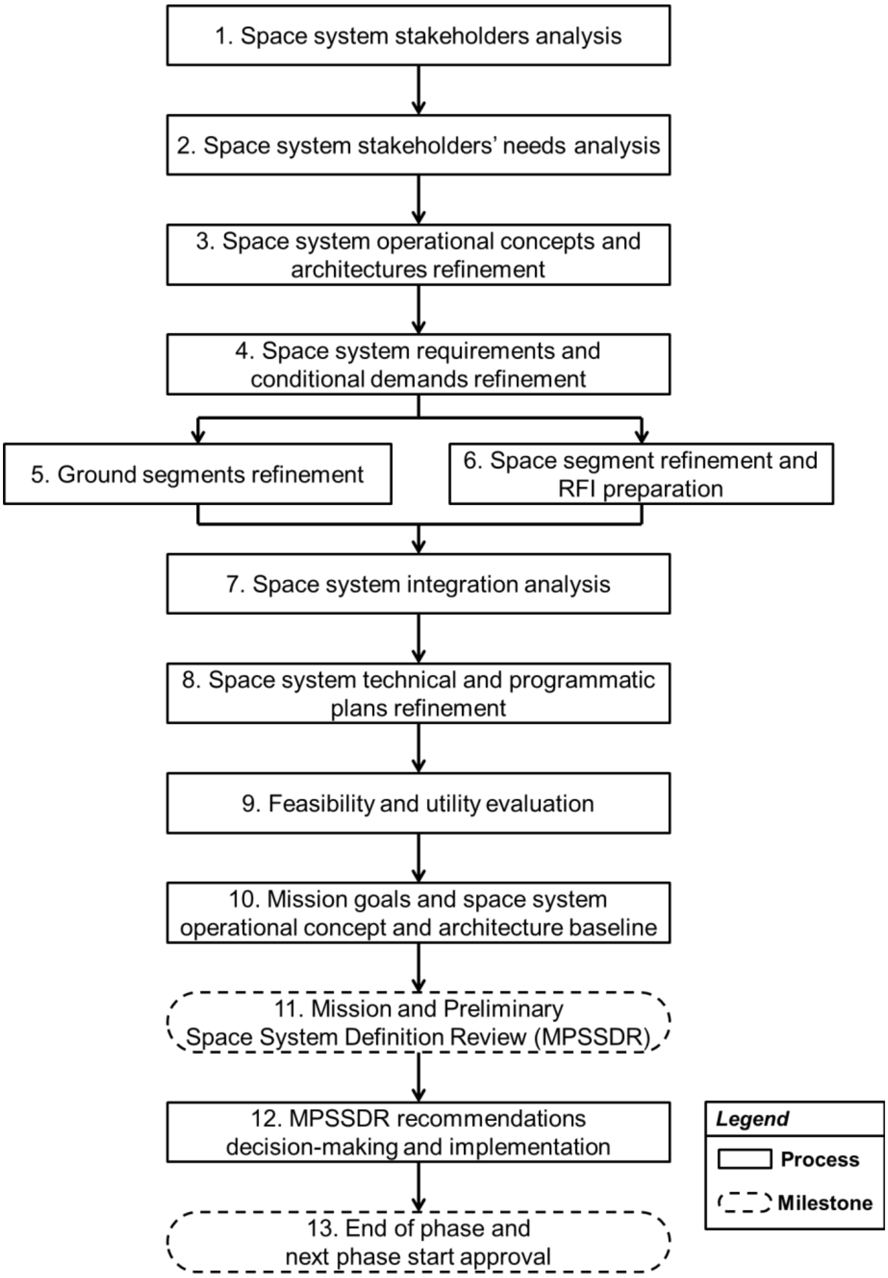
- Obtain preliminary information about the turnkey space segment solutions available on the market;
- Refine the space system concept alternatives (including requirements, conditional demands, and plans) according to market characteristics;
- Perform a detailed assessment of the feasibility and utility and the space system concept alternatives according to market characteristics;
- Baseline the space system concept (i.e. space system operational concept and architecture);
- Baseline the mission goals (i.e. requirements and conditional demands).

During the current phase, main effort should be placed upon the processes that are related to the definition of space segment and its systems (i.e. satellites). Processes related to the definition of the ground segments should be performed within this phase to ensure that such segments will be compatible with the defined space segment and its systems.

3.2.2.2 Phase 2 processes and milestones

Figure 3.20 shows a flowchart of the SPSYSE-TK methodology within this phase. Rectangle boxes indicate processes, while rounded boxes with dashed lines indicate milestones (e.g. reviews). Processes that are in parallel or in series can (and ideally, should) involve iterations between them.

Figure 3.20 - Phase 2 of the SPSYSE-TK methodology.



Source: Author production.

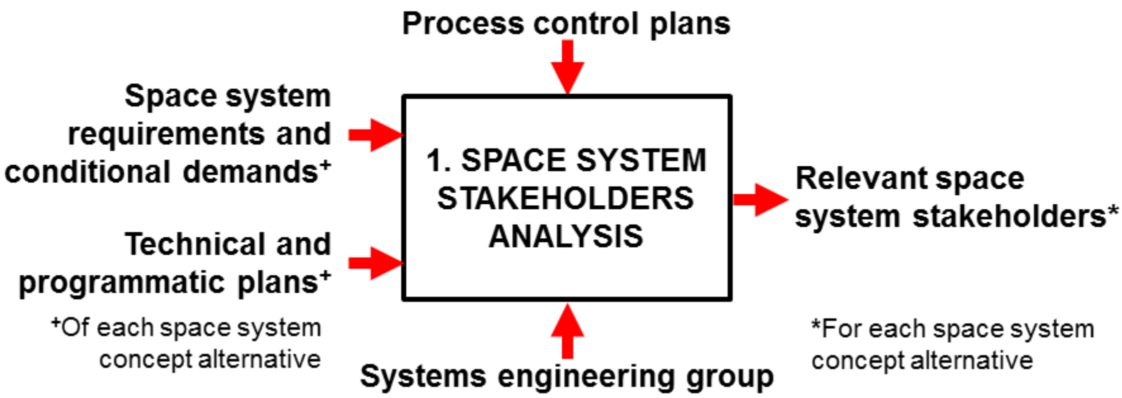
Following subsections describe the objectives and the recommended activities for each process and milestone within this phase.

3.2.2.2.1 Space system stakeholders analysis

This process consists in defining the relevant stakeholders of the space system (i.e. those who will have more influence and the power to resolve issues related to the space system) for each space system concept alternative.

This process begins with the space system requirements, conditional demands, and plans of each space system concept alternative that advanced to the current phase. At the end of this process, the systems engineering group should have identified and ranked the relevant stakeholders that can influence the definition of the space system for each space system concept alternative. Figure 3.21 illustrates the IDEF0 representation of this process.

Figure 3.21 - IDEF0 representation of the 'mission stakeholders analysis' process.



Source: Author production.

Specifically, this process should include the following tasks:

a. Identify the space system stakeholders for a space system concept alternative (e.g. customer, developers, manufacturers, regulatory agencies, operators, users);
b. Define the relevant stakeholders for the space system concept alternative;

c. If possible, rank the relevant stakeholders;
d. Repeat from a. to c. for each space system concept alternative.

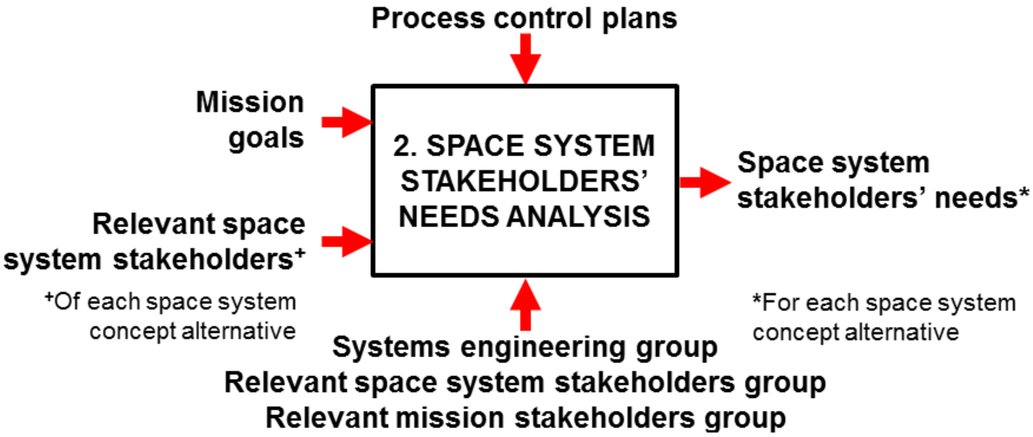
Space system stakeholders can be identified based on the lifecycle stages, or by other method such as brainstorming or stakeholder influence maps.

3.2.2.2.2 Space system stakeholders' needs analysis

This process consists in defining a consistent set of needs for each space system concept alternative.

This process begins with the list of relevant and ranked space system stakeholders. At the end of this process, the systems engineering group should have gathered and refined a set of space system stakeholders' needs in order to make them consistent not only among them but also with mission goals. Consistent needs are those free of conflict with another need. During this process, ambiguous needs are unlikely to occur since space system stakeholders (oppositely to mission stakeholders) are assumed to have the knowledge and skills to define their needs without ambiguity. Figure 3.22 illustrates the IDEF0 representation of this process.

Figure 3.22 - IDEF0 representation of the 'space system stakeholders' needs analysis' process.



Source: Author production.

Specifically, this process should include the following tasks:

a. Elicit needs from the relevant space system stakeholders of a space system concept alternative;
b. Review the space system stakeholders’ needs;
c. Identify implicit needs;
d. Identify inconsistent needs;
e. Resolve inconsistent needs (together with the relevant mission and space system stakeholders);
f. Repeat from a. to e. for each space system concept alternative.

In this process, it is recommended to have several iterations with the space system stakeholders to understand and refine the declared needs as well as new identified needs. It is also recommended to look for other potential needs that the space system stakeholders might have not perceived or declared. It is possible that some space system needs were actually identified during the previous phase. However, new needs might appear during this process. Any need gathered during this process might affect the technical or programmatic definition of the space system concept alternatives that was previously performed.

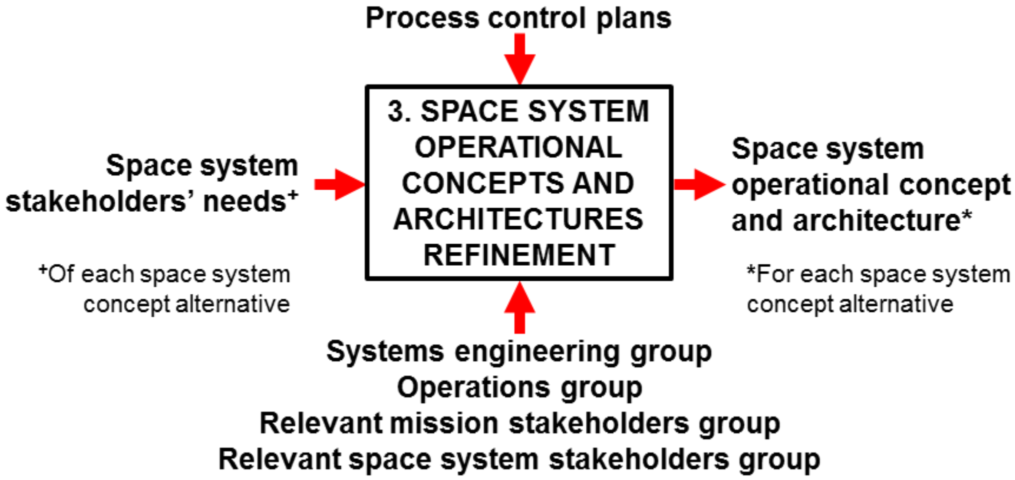
During this process, needs coming from the space system stakeholders can conflict with the mission goals. As an example, the spatial resolution might be required to be 30 cm or less. However, local government might have a law that forbids such kind of resolutions from the air and space. Consequently, it is recommended to involve the most relevant mission and space system stakeholders in the decision-making about inconsistent needs.

3.2.2.2.3 Space system operational concepts and architectures refinement

This process consists in refining the operational concept and the architecture of each space system concept alternative in accordance with accepted space system stakeholders’ needs.

This process begins with the refined space system stakeholders' needs of each space system concept alternative. At the end of this process, the systems engineering group should have refined the space system operational concept and architecture for each space system concept alternative. Figure 3.23 illustrates the IDEF0 representation of this process.

Figure 3.23 - IDEF0 representation of the 'space system operational concepts and architectures refinement' process.



Source: Author production.

Specifically, this process should include the following tasks:

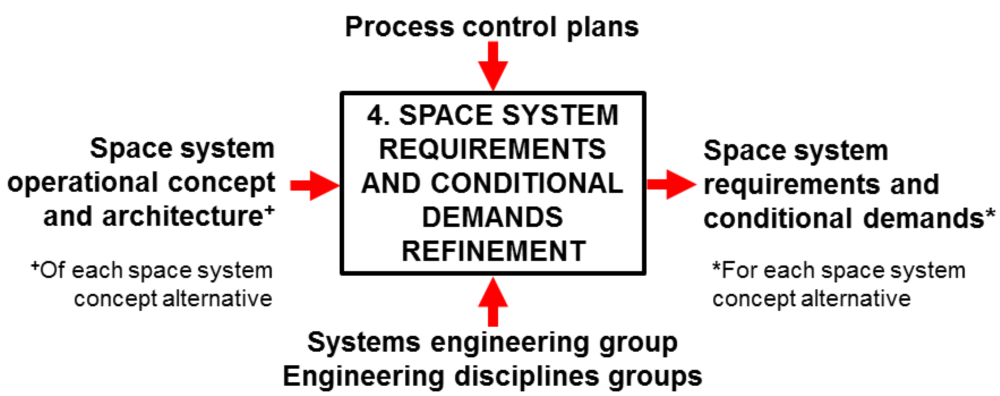
a. Review the space system stakeholders' needs to identify how they would impact the operational concept and the architecture of the related space system concept alternative;
b. Assess the fulfillment of each need into the space system concept alternative (together with the relevant mission and space system stakeholders);
c. Refine the space system operational concept and the architecture in accordance with the accepted needs;
d. Repeat from a. to c. for each space system concept alternative.

3.2.2.2.4 Space system requirements and conditional demands refinement

This process consists in refining the space system requirements and conditional demands of each space system concept alternative in accordance with the refined operational concept and architecture.

This process begins with the space system concept alternatives. At the end of this process, the systems engineering group should have refined the set of requirements and conditional demands for each space system concept alternative. Figure 3.24 illustrates the IDEF0 representation of this process.

Figure 3.24 - IDEF0 representation of the 'space system requirements refinement and conditional demands' process.



Source: Author production.

Specifically, this process should include the following tasks:

a. Review the refined operational concept and architecture to identify updates on the previously established characteristics or to identify new required or desired characteristics that the major elements of the space system (i.e. segments and segment systems) are expected to have or do;
b. If not determined yet, define how the fulfillment of each new required or desired characteristic will be assessed (i.e. technical measures);
c. If not determined yet, define the minimum success criteria (based on the technical measures) to meet each required characteristic;
d. Update the space system requirements;

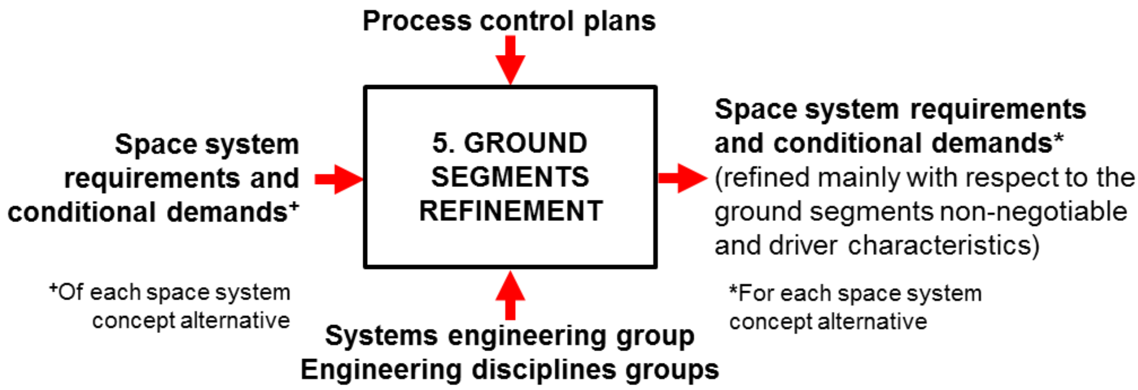
e. If applicable and not determined yet, define the preferred values (based on the technical measures) for each new desired characteristic;
f. Update the space system conditional demands;
g. Repeat from a. to g. for each space system concept alternative.

3.2.2.2.5 Ground segments refinement

This process consists in identifying the non-negotiable and driver characteristics of the ground segments and their systems of each space system concept alternative.

This process begins with the refined requirements and conditional demands of each space system concept alternative. At the end of this process, the systems engineering group should have refined such set of requirements and conditional demands for each space system concept alternative, highlighting mainly the ground segments non-negotiable and driver characteristics. Figure 3.25 illustrates the IDEF0 representation of this process.

Figure 3.25 - IDEF0 representation of the ‘ground segments refinement’ process.



Source: Author production.

Specifically, this process should include the following tasks:

a. Review the space system requirements and conditional demands to identify already defined or potential characteristics of a ground segment and its systems that may affect the space segment and are likely to be non-negotiable or driver features;

b. Harmonize the non-negotiable or driver features of the ground segment with the space segment and its systems (i.e. satellites) requirements and conditional demands;
c. Repeat a. and b. for each ground segment;
d. Repeat from a. to c. for each space system concept alternative.

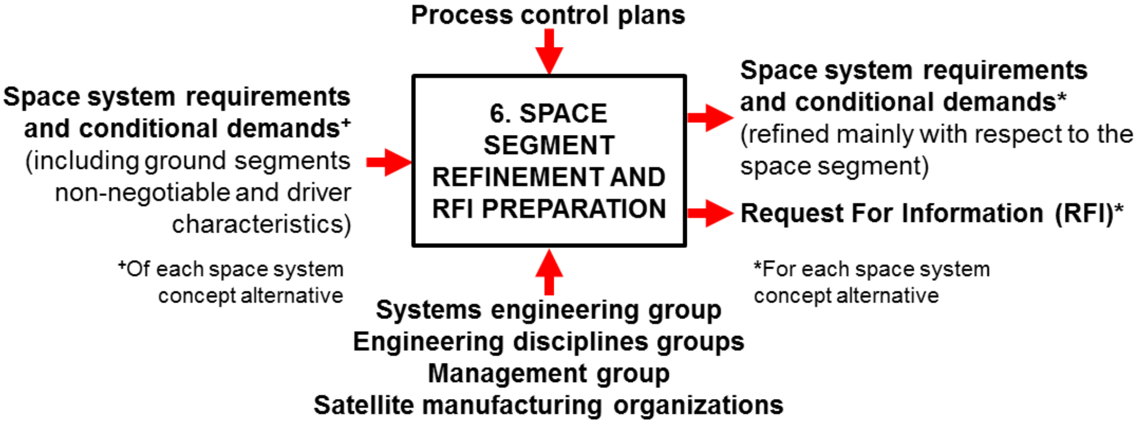
In this process, the focus is not on detailing ground segments characteristics. Instead, the focus is on identifying non-negotiable or potential driver characteristics that could derive in requirements or conditional demands for the space segment. Examples of ground segments characteristics are frequency band, transmitted power, receiver sensitivity, data protocol, interfaces, data storage capability, data rate, operational aspects (e.g. timelines, procedures), latency, antenna gain-to-noise-temperature (G/T), data processing capability, cost, schedule, availability, location, and autonomy.

3.2.2.2.6 Space segment refinement and RFI preparation

This process consists in producing a Request For Information (RFI) with the main required and desired characteristics of the space segment and its systems (i.e. satellites) of each space system concept alternative.

This process begins with the refined requirements and conditional demands (including the ground segments non-negotiable and driver characteristics) of each space system concept alternative. At the end of this process, the systems engineering group should have refined such set of requirements and conditional demands with respect to the space segment for each space system concept alternative. Figure 3.26 illustrates the IDEF0 representation of this process.

Figure 3.26 - IDEF0 representation of the 'space segment refinement and RFI preparation' process.



Source: Author production.

Specifically, this process should include the following tasks:

a. Review the space system requirements and conditional demands to identify new required or desired characteristics of the space segment and its systems (i.e. satellites);
b. Harmonize the identified characteristics (both required and desired) of the space segment and its systems (i.e. satellites) with the non-negotiable or driver characteristics identified for the ground segments and their systems;
c. Establish the space segment requirements and conditional demands;
d. Support the preparation of the RFI;
e. Support the distribution of the RFI;
f. Support answers and clarifications related to the RFI to manufacturers;
g. Repeat from a. to f. for each space system concept alternative.

Space segment characteristics (both required and desired) can be preliminary in this phase. Examples of space segment characteristics are the number of satellites; orbits; schedule; cost; lifetime; reliability; availability; autonomy; maturity level; ground sample distance; focal length; field of view; data rate; number of transponders; frequencies and bandwidth of transponders; data protocol; data storage capability; compression/decompression capability;

encryption/decryption capability; stationkeeping capabilities; stability; Equivalent Isotropically Radiated Power (EIRP); pointing control capacity; pointing control accuracy; pointing control knowledge; transmission/reception frequencies; payload data transmission/reception frequencies; operational modes; data generation capabilities; flight experience; delta-V; duty cycle; attitude and orbit determination and control.

The RFI produced in this process should ask, at maximum, for two preliminary turnkey proposals:

- One that at least meets the space segment requirements;
- Other that meets the space segment requirements and the maximum number of the space segment conditional demands. In case of fulfilling all the conditional demands, and having more than one proposal within this condition, the proposal should be the one with the fewer number of additional (or unrequested) characteristics. Otherwise, costs might increase without adding value to the mission.

The use of those two different proposals will help to estimate the boundaries between the best and the worst-case scenarios while keeping the number of proposals manageable.

The RFI should ask the Rough Order of Magnitude (ROM) of the cost, schedule, and performance characteristics of the proposed solutions with respect to the requirements and conditional demands that are sent to the manufacturers.

The RFI can have additional questions related to aspects such as manufacturer' restrictions (e.g. International Traffic in Arms Regulations or ITAR), maturity or flight experience of the preliminary proposals, possibility to transfer knowledge or to provide services before the delivery of the satellites.

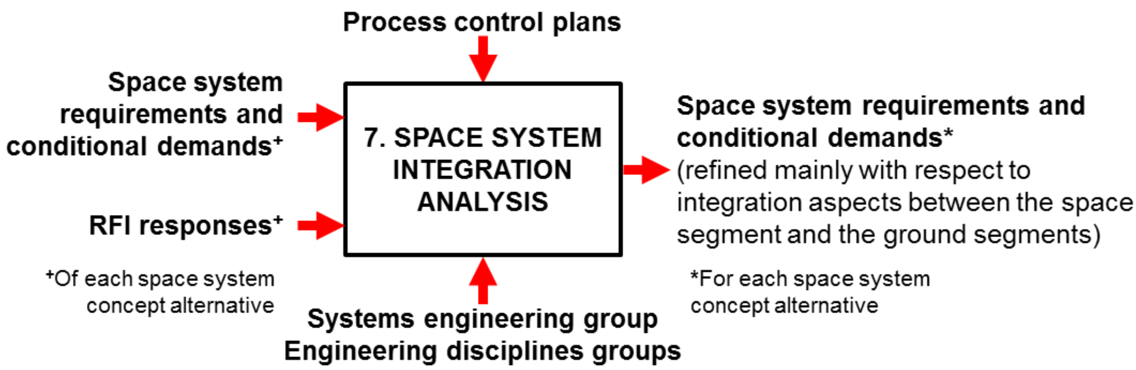
The RFI may also ask only for proposals within one or several constraints, such as cost, delivery time, or minimum maturity level.

3.2.2.2.7 Space system integration analysis

This process consists in refining the space and ground segments requirements and conditional demands in accordance with the information gathered from the RFI responses and with a subsequent analysis of the integration aspects among the space segment and the ground segments of each space system concept alternative.

This process begins with the previously refined space system requirements and conditional demands and the RFI responses of each space system concept alternative. At the end of this process, the systems engineering group should have refined such set of requirements and conditional demands with respect to integration aspects between the space segment and the ground segments for each space system concept alternative. Figure 3.27 illustrates the IDEF0 representation of this process.

Figure 3.27 - IDEF0 representation of the ‘space system integration analysis’ process.



Source: Author production.

Specifically, this process should include the following tasks:

a. Review the RFI responses to recognize new potential characteristics (required or desired) for both the space segment and the ground segments (e.g. previously non-defined interfaces, unidentified functions, improper allocated requirements, unlikely performance);

b. Assess the insertion of the new potential characteristics as requirements or conditional demands for any of the segments;
c. Update the space system, space segment, and ground segments requirements and conditional demands in accordance with the new required or desired characteristics;
d. Repeat from a. to c. for each space system concept alternative.

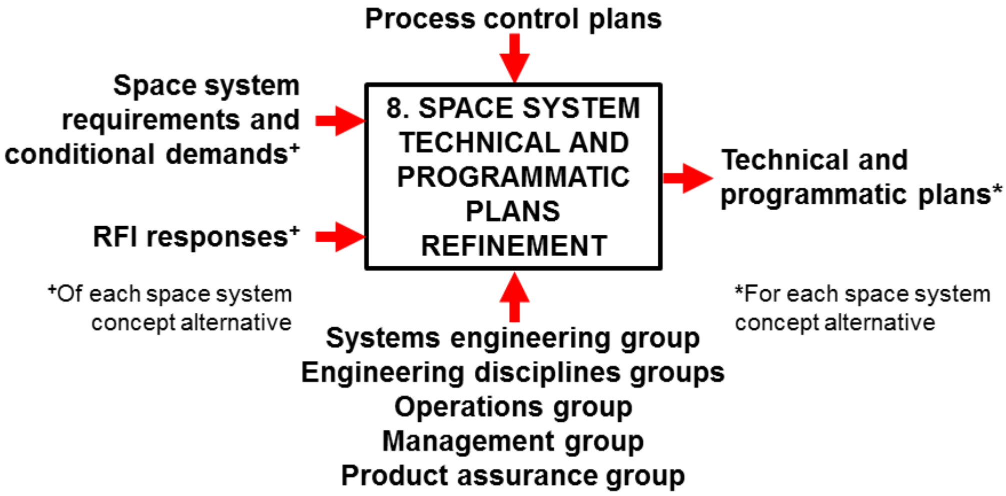
The space segment and ground segments characteristics (both required and desired) can still be preliminary.

3.2.2.2.8 Space system technical and programmatic plans refinement

This process consists in refining the preliminary plans that were developed in the previous phase in accordance with the information gathered from the RFI responses for each space system concept alternative (including programmatic aspects).

This process begins with the previously refined space system requirements and conditional demands and the RFI responses of each space system concept alternative. At the end of this process, the systems engineering group should have refined the technical and programmatic plans with respect to the RFI responses and the updates in the space system requirements and conditional demands for each space system concept alternative. Figure 3.28 illustrates the IDEF0 representation of this process.

Figure 3.28 - IDEF0 representation of the 'space system technical and programmatic plans refinement' process.



Source: Author production.

Specifically, this process should include the following tasks:

a. Review the RFI responses to identify required changes in the preliminary plans that were developed in the previous phase;
b. Refine the systems engineering plan for the subsequent phases in accordance with the required changes, focusing on activities of the following phase;
c. Support the refinement of the other existing plans for the subsequent phases in accordance with the required changes, focusing on the following phase;
d. Identify if additional technical and programmatic plans shall be developed (e.g. risk assessment plan, decision management plan, procurement plan);
e. Support the definition of the new plans for the subsequent phases, focusing on activities of the following phase;
f. Review the RFI responses to update the programmatic aspects of the space system concept alternative;
g. Repeat from a. to f. for each space system concept alternative.

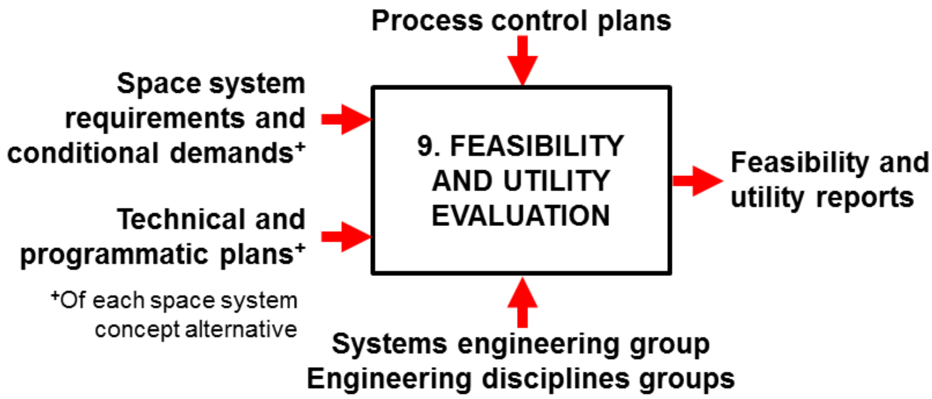
In this process, new technical and programmatic plans may be identified. The use of real information coming from the RFI responses allows establishing more accurate estimations of programmatic aspects and more realistic plans.

3.2.2.2.9 Feasibility and utility evaluation

This process consists in assessing the feasibility and utility of the different space system concept alternatives.

This process inputs the space system requirements and conditional demands as well as the plans of each space system concept alternative. At the end of this process, the systems engineering group should have produced a set of feasibility and utility results. Utility results should be used in the next process to select a baseline space system concept. Figure 3.29 illustrates the IDEF0 representation of this process.

Figure 3.29 - IDEF0 representation of the 'feasibility and utility evaluation' process.



Source: Author production.

Specifically, this process should include the following tasks:

a. Assess the technical feasibility of a space system concept alternative;
b. Assess the programmatic feasibility of the space system concept alternative;
c. Repeat a. and b. for each space system concept alternative;
d. Discard unfeasible alternatives;

e. Assess the mission utility of the feasible space system concept alternatives.

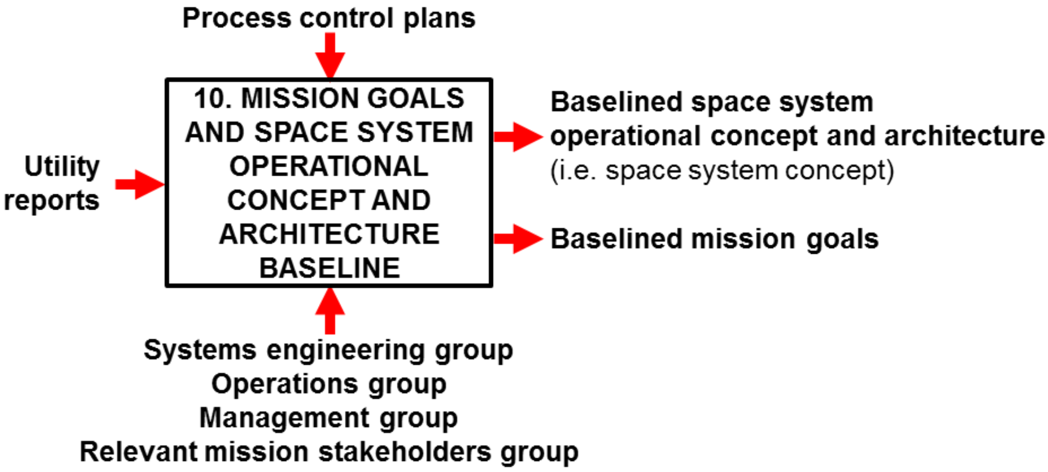
Criteria for selecting among alternatives should be defined together with the relevant mission stakeholders and can be different from those used in phase 1.

3.2.2.2.10 Mission goals and space system operational concept and architecture baseline

This process consists in baselining the mission goals (i.e. mission requirements and conditional demands) as well as the space system operational concept and architecture (i.e. space system concept).

This process inputs the utility results. At the end of this process, the systems engineering group should have established the baselines of the mission goals and the space system operational concept and architecture (i.e. space system concept). Figure 3.30 illustrates the IDEF0 representation of this process.

Figure 3.30 - IDEF0 representation of the 'mission goals and space system operational concept and architecture baseline' process.



Source: Author production.

Specifically, this process should include the following tasks:

a. Review the mission utility results of the feasible space system concept alternatives to identify the proper for the current mission (together with relevant mission stakeholders);
b. Baseline the space system concept (i.e. space system operational concept and architecture);
c. Review the mission goals in accordance to the baselined space system concept to refine and agree exactly on what the mission shall accomplish (i.e. mission requirements) and what will add more value to the mission but it is not mandatory (i.e. mission conditional demands) (together with relevant mission stakeholders);
d. Baseline the mission goals.

In this process, it is recommended to have several iterations with the mission stakeholders to discuss and validate the selection of both the space system concept and the mission goals. The space system concept and the mission goals were chosen to be baselined in this phase since the information herein should be accurate and realistic in technical and programmatic terms.

3.2.2.2.11 Mission and Preliminary Space System Definition Review (MPSSDR)

This milestone represents a review of the most important outcomes that have been produced within this phase; specifically, the baselined mission goals and the baselined space system concept (including its requirements, conditional demands, plans, and the mission utility results that justify its selection). This review should be performed by external group of specialists with the appropriate knowledge and experience to judge the content that has been produced in this phase. The systems engineering group should participate in the review to provide clarifications, assess recommendations (together with the relevant mission stakeholders), and implement recommendations when required.

The primary objectives of this milestone are:

a. Assess the baselined mission goals and the baselined space system concept, which includes the space system requirements, conditional demands, plans, and the mission utility results that justify its selection;
b. Establish recommendations showing issues such as unidentified errors, incomplete information, unfeasible requirements, inaccurate plans, and potential actions;
c. If possible during the review, assess the implementation of some of the recommendations (together with the relevant mission stakeholders);
d. If possible during the review, implement some of the accepted recommendations.

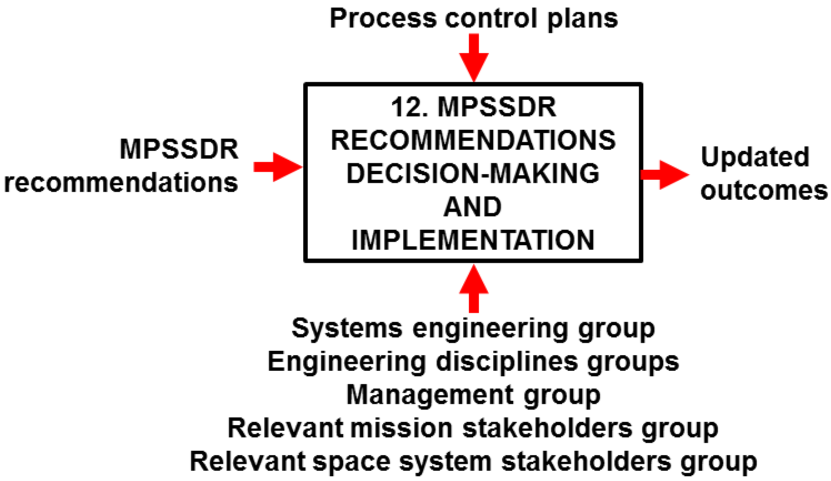
The idea of this review is to ensure that the space system concept and the mission goals are realist and consistent with market characteristics, and consequently, they were correctly baselined before proceeding to the next phase.

3.2.2.2.12 MPSSDR recommendations decision-making and implementation

This process consists in assessing and implementing some of the recommendations that were produced during the MPSSDR but were not assessed or implemented during such review.

This process inputs the recommendations of the MPSSDR. At the end of this process, the systems engineering group should have update the outcomes of this phase with the accepted recommendations of the MPSSDR. Figure 3.31 illustrates the IDEF0 representation of this process.

Figure 3.31 - IDEF0 representation of the 'MPSSDR recommendations decision-making and implementation' process.



Source: Author production.

Specifically, this process should include the following tasks:

a. Assess the implementation of the recommendations that were not assessed during the MPSSDR (together with the relevant mission stakeholders);
b. Implement the accepted recommendations that were not implemented during the MPSSDR or those that were accepted in a.

3.2.2.2.13 End of phase and next phase start approval

This milestone represents the end of the current phase and the start of the next phase. The outcomes of the current phase should be approved and released. Then, the systems engineering group should be authorized to begin the effort of the next phase as a result of this milestone.

The primary objectives of this milestone are:

a. Obtain written approval from higher-level authorities to close the current phase;
b. Release the outcomes of this phase;
c. Obtain written approval from higher-level authorities to begin the next phase and use the allocated resources during the following phase.

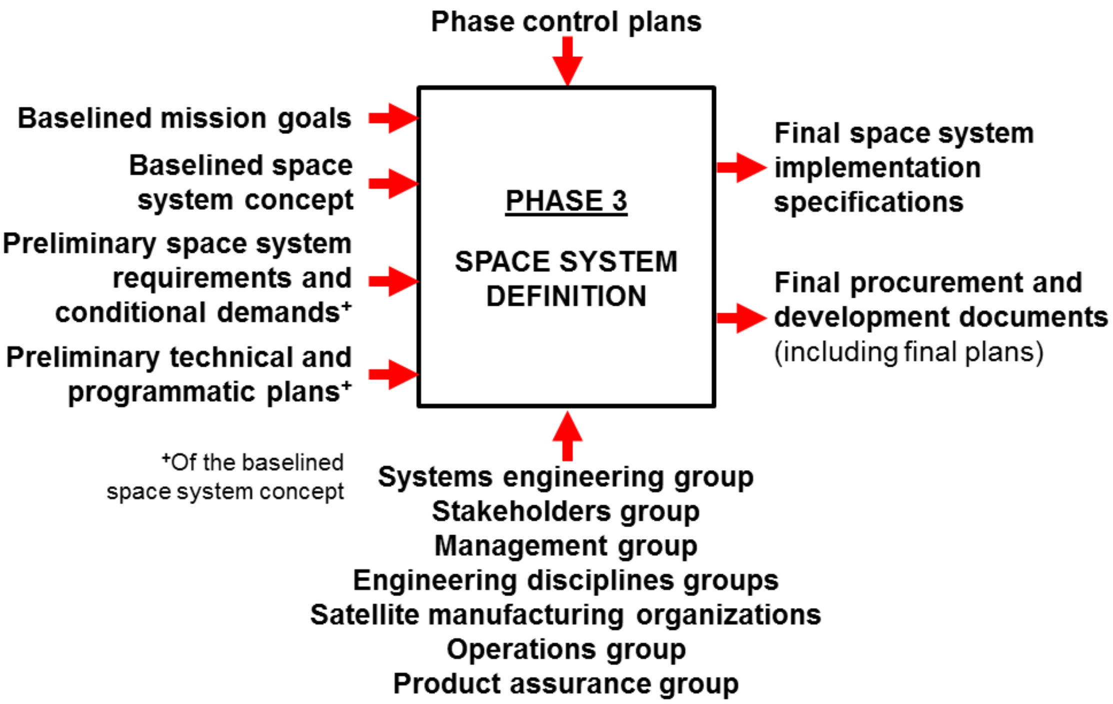
3.2.3 **Phase 3: space system definition**

3.2.3.1 Phase 3 objectives

The main objective of this phase is to define (in a final way) the space system that will perform the mission.

This phase begins with the reviewed and approved outputs of the previous phase. At the end of this phase, the systems engineering group should have produced the final space system implementation specifications (detailed definition of the space system) and the final set of documents for the procurement and development of the systems that constitute the segments (including their final plans). Figure 3.32 illustrates the IDEF0 representation of this phase.

Figure 3.32 - Phase 3 IDEF0 representation.



Source: Author production.

The specific objectives of this phase within the systems engineering effort are:

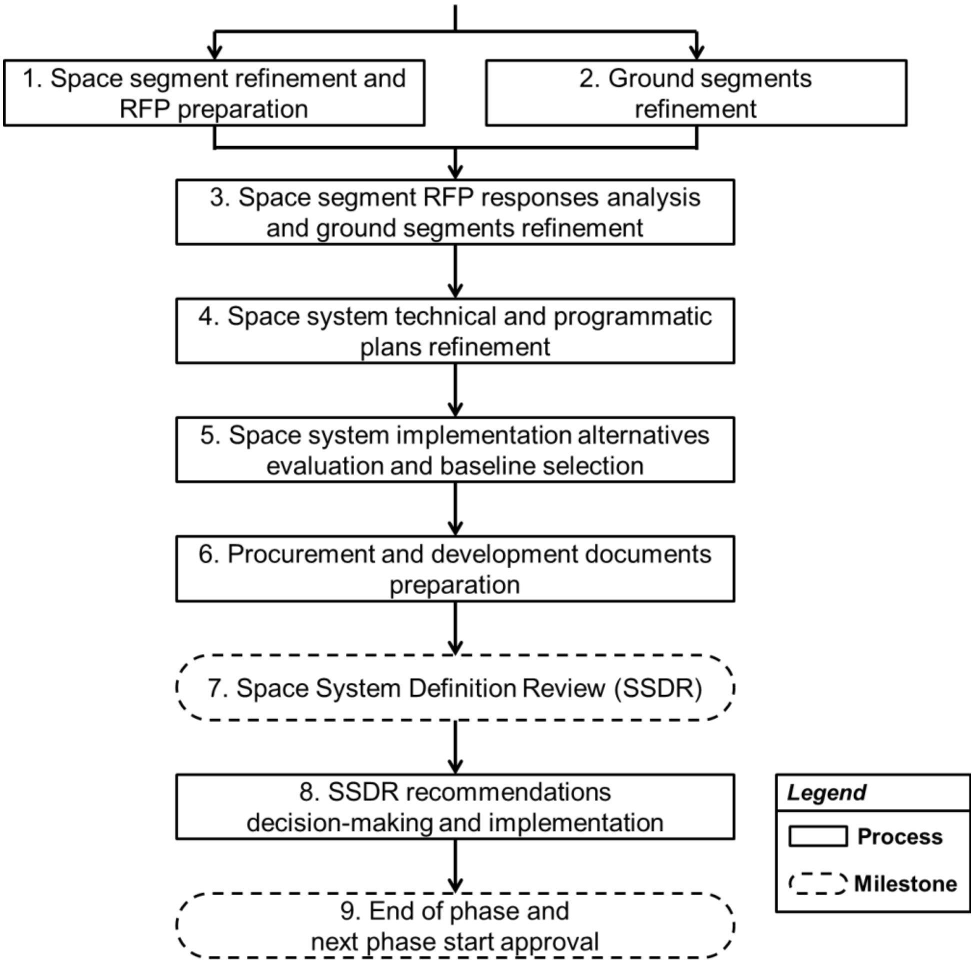
- Obtain detailed proposals for the space segment;
- Obtain detailed proposals for the ground segments;
- Establish some space system implementation alternatives (i.e. combination of proposals of the space and the ground segments);
- Perform a detailed assessment of the mission utility of the several space system implementation alternatives;
- Selection of a space system implementation alternative;
- Support the preparation of procurement documents that will be needed to buy the selected turnkey space segment solution as well as other documents that will be needed to make or buy the ground segments (including final technical and programmatic plans).

During the current phase, all the segments should be defined in detail. Consequently, the segments and their systems will have all the information, relative to their functional and physical architectures and to their characteristics, necessary for its procurement, development, production, utilization, support, configuration management, and removal from service (e.g. technical specifications, design and interface descriptions, drawings, electrical schematics).

3.2.3.2 Phase 3 processes and milestones

Figure 3.33 shows a flowchart of the SPSYSE-TK methodology within this phase. Rectangle boxes indicate processes, while rounded boxes with dashed lines indicate milestones (e.g. reviews). Processes that are in parallel or in series can (and ideally, should) involve iterations between them.

Figure 3.33 - Phase 3 of the SPSYSE-TK methodology.



Source: Author production.

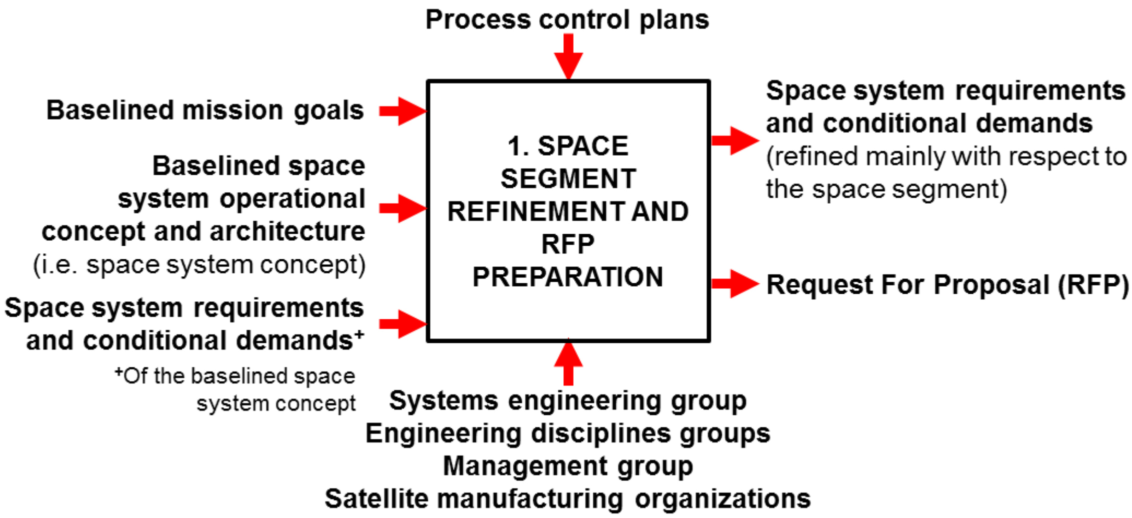
Following subsections describe the objectives and the recommended activities for each process and milestone within this phase.

3.2.3.2.1 Space segment refinement and RFP preparation

This process consists in producing a Request For Proposal (RFP) with the requirements and conditional demands of the space segment and its systems (i.e. satellites) in harmonization with the ground segments requirements and conditional demands.

This process begins with the baselined mission goals, the baselined space system concept, and the latest set of space system requirements and conditional demands of the baselined concept. At the end of this process, the systems engineering group should have refined such set of requirements and conditional demands with respect to the space segment and in harmonization with the ground segments. Figure 3.34 illustrates the IDEF0 representation of this process.

Figure 3.34 - IDEF0 representation of the 'space segment refinement and RFP preparation' process.



Source: Author production.

Specifically, this process should include the following tasks:

a. Review the baselined mission goals (i.e. mission requirements and conditional demands) and space system concept (i.e. space system operational concept and architecture) to refine the required or desired characteristics of the space segment and its systems (i.e. satellites);
b. Harmonize the already identified characteristics (both required and desired) of the space segment and its systems (i.e. satellites) with the characteristics of the ground segments and their systems;
c. Refine the space segment requirements and conditional demands;
d. Support the preparation of the RFP;
e. Support the distribution of the RFP;
f. Support answers and clarifications related to the RFP to manufacturers.

Space segment characteristics (both required and desired) should be final in this phase.

The RFP produced in this process should ask for all (or at least the most relevant at the discretion of each manufacturer) the turnkey proposals that are within the following constraints:

- Fulfillment of at least the space segment requirements;
- Fulfillment at maximum the space segment requirements, all the space segment conditional demands, and the fewer number of additional (or unrequested) characteristics. Otherwise, costs might increase without adding value to the mission.

The RFP shall ask the exact cost, schedule, and performance characteristics of the proposed solutions with respect to the requirements and conditional demands that are sent to the manufacturer.

The RFP can also ask the exact maturity of flight experience for the proposals, or any additional questions that can be considered as selection criteria (e.g. clauses for transferring knowledge or providing services before the delivery of the satellites, launch service availability, minimum delivery time, associated risks of the satellite and the launch provider, clauses for satellite insurance).

The RFP may also ask only for proposals within one or several constraints, such as cost, delivery time, or minimum maturity level.

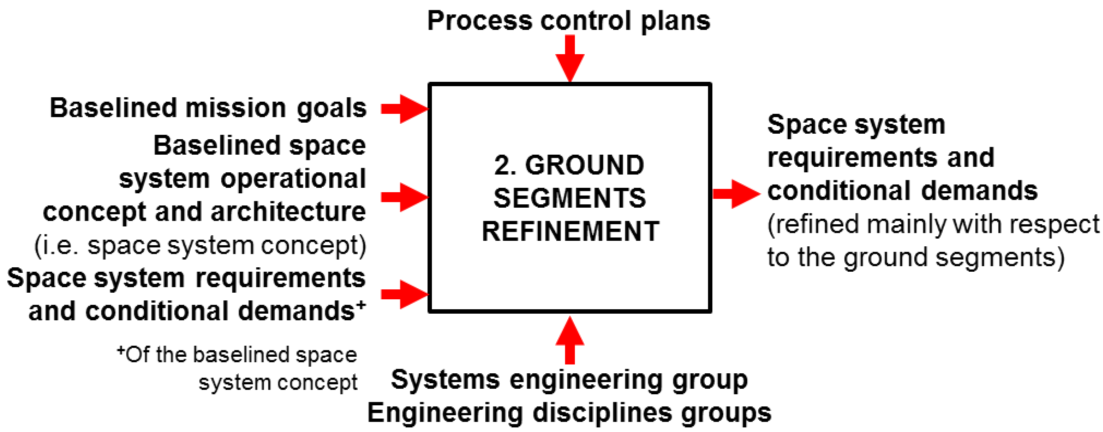
Finally, the RFP could be sent only to manufacturers that answered to the RFI in the previous phase.

3.2.3.2.2 Ground segments refinement

This process consists in refining the ground segments requirements and conditional demands in harmonization with the space segment requirements and conditional demands.

This process begins with the baselined mission goals, the baselined space system concept, and the latest set of space system requirements and conditional demands of the baselined concept. At the end of this process, the systems engineering group should have refined such set of requirements and conditional demands with respect to the ground segments and in harmonization with the space segment. Figure 3.35 illustrates the IDEF0 representation of this process.

Figure 3.35 - IDEF0 representation of the 'ground segments refinement' process.



Source: Author production.

Specifically, this process should include the following tasks:

a. Review the baselined mission goals (i.e. mission requirements and conditional demands) and space system concept (i.e. space system operational concept and architecture) to refine the required or desired characteristics of a ground segment and its systems;
b. Harmonize the already identified characteristics (both required and desired) of the ground segment and its systems with the characteristics of the space segment and its systems (i.e. satellites);
c. Refine the ground segment requirements and conditional demands;
d. Repeat from a. to c. for each ground segment.

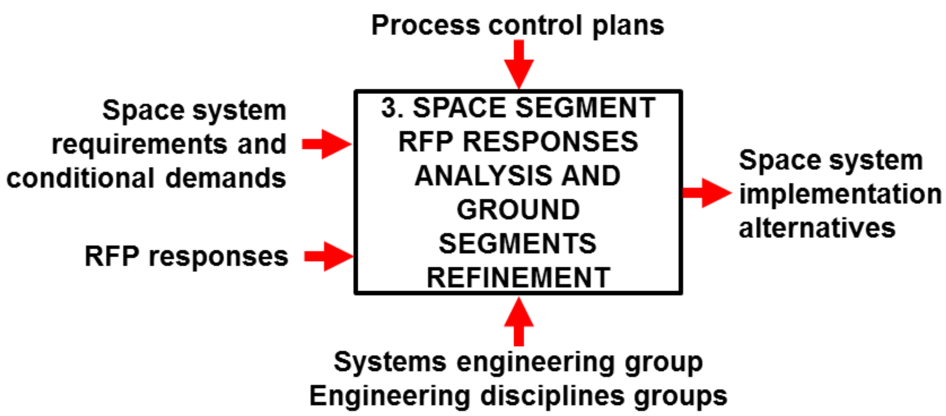
In this process, the focus is not on detailing ground segments characteristics. The focus is on refining ground segments characteristics to ensure harmonization with the characteristics of the space segment that will be placed on the RFP.

3.2.3.2.3 Space segment RFP responses analysis and ground segments refinement

This process consists in producing several space system implementation alternatives in accordance with the turnkey space segment solutions that were received in response to the RFP and the subsequent refinement of the ground segments characteristics (for the ground segments within the systems engineering effort).

This process begins with the space system requirements and conditional demands and the RFP responses of each space system concept alternative. At the end of this process, the systems engineering group should have produced a set of space system implementation alternatives combining the proposals of the space segment that come from the RFP responses with proposals of ground segments that should be defined during this process by other group or organization. Figure 3.36 illustrates the IDEF0 representation of this process.

Figure 3.36 - IDEF0 representation of the 'space segment RFP responses analysis and ground segments refinement' process.



Source: Author production.

Specifically, this process should include the following tasks:

a. Review the RFP responses to recognize new characteristics (required or desired) for a ground segment and its systems;

b. Support the establishment of proposals for the ground segment by any other group or organization with the necessary skills;
c. Repeat a. and b. for each ground segment to be specified;
d. Establish some space system implementation alternatives (i.e. proposed space segment and ground segments).

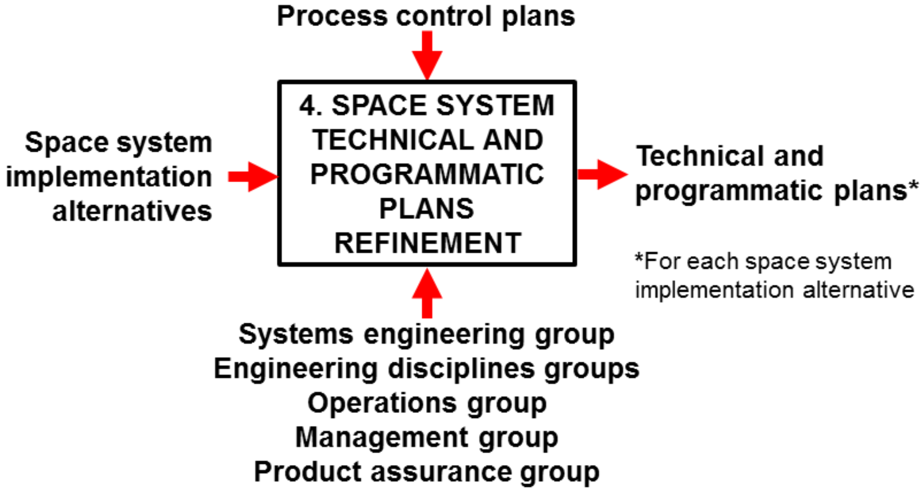
In this process, the focus is on detailing ground segments characteristics in accordance with the RFP responses and space system requirements and conditional demands. Such details related to ground segments should come from other organizations or groups that will be responsible for such segments. Ground segments proposals should be detailed and equivalent to the RFP responses obtained from turnkey satellites manufacturers. Consequently, the space system implementation alternatives would be detailed enough to be identified, procured, manufactured, utilized, supported, and removed from service.

3.2.3.2.4 Space system technical and programmatic plans refinement

This process consists in refining the plans that were developed in the previous phase in accordance with the updated information for each space system implementation alternative (including programmatic aspects).

This process begins with the space system implementation alternatives. At the end of this process, the systems engineering group should have refined the technical and programmatic plans (including programmatic aspects) with respect to the detailed segments proposals for each space system implementation alternative. Figure 3.37 illustrates the IDEF0 representation of this process.

Figure 3.37 - IDEF0 representation of the 'space system technical and programmatic plans refinement' process.



Source: Author production.

Specifically, this process should include the following tasks:

a. Review a space system implementation alternative (i.e. proposed space segment and ground segments) to identify required changes in the preliminary plans that were developed in the previous phase;
b. Establish the detailed systems engineering plan for the subsequent phases in accordance with the required changes;
c. Support the refinement of the other existing plans for the subsequent phases in accordance with the required changes;
d. Identify if additional technical and programmatic plans shall be developed (e.g. payment plan);
e. Support the definition of the new plans for the subsequent phases;
f. Review the segments proposals of the space system implementation alternative to update its programmatic aspects;
g. Repeat from a. to f. for each space system implementation alternative.

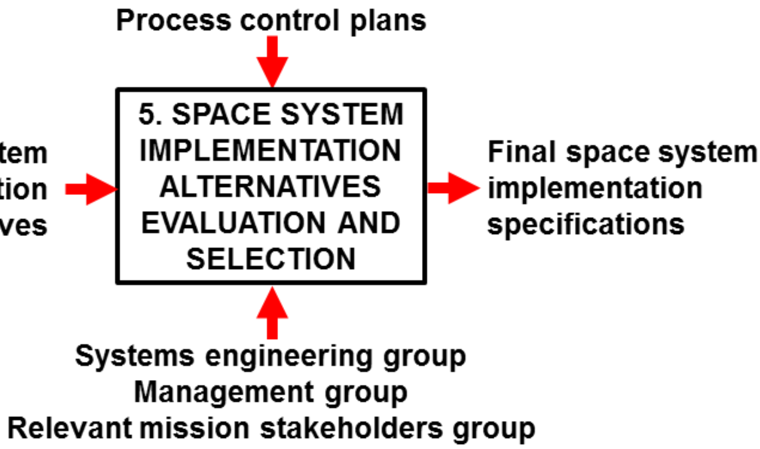
In this process, new technical and programmatic plans may be identified. The use of detailed information coming from the proposals of both the space segment and the ground segments allows determining detailed programmatic aspects and establishing more detailed plans.

3.2.3.2.5 Space system implementation alternatives evaluation and selection

This process consists in selecting the space system implementation after assessing the mission utility of the programmatically feasible alternatives.

This process inputs the space system implementation alternatives. At the end of this process, the systems engineering group should have established the final space system implementation specifications (for the segments and their systems). Figure 3.38 illustrates the IDEF0 representation of this process.

Figure 3.38 - IDEF0 representation of the ‘space system implementation alternatives evaluation and selection’ process.



Source: Author production.

Specifically, this process should include the following tasks:

a. Assess the programmatic feasibility of a space system implementation alternative;
b. Repeat a. for each space system implementation alternative;
c. Discard unfeasible alternatives;
d. Assess the mission utility of the feasible space system implementation alternatives;
e. Select the space system implementation with the highest utility value.

Criteria for selecting among alternatives should be defined together with the relevant mission stakeholders and can be different from the used in phases 1 and 2.

In this process, it is recommended to have several iterations with the mission stakeholders to discuss and validate the selection of the space system implementation.

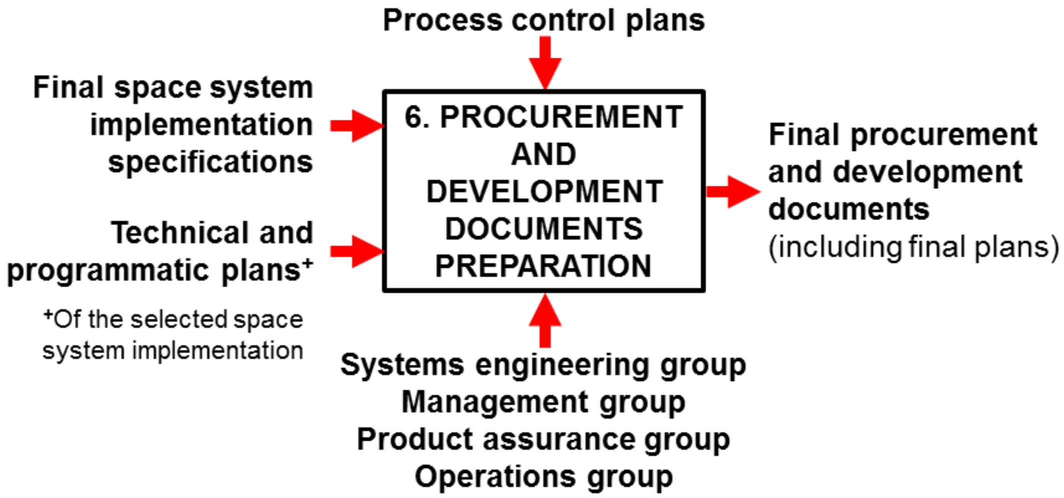
The final space system implementation specifications represent the detailed definition of the space system. It should contain all the information relative to the space system (and its elements), necessary for its procurement, development, production, utilization, support, configuration management, and removal from service.

3.2.3.2.6 Procurement and development preparation

This process consists in finalizing the preparation for the procurement and the development efforts that will be needed to produce the selected space system implementation.

This process inputs the final space system implementation requirements and its associated technical and programmatic plans. At the end of this process, the systems engineering group should have supported the finalization of procurement and development documents (for the segments and their systems). Figure 3.39 illustrates the IDEF0 representation of this process.

Figure 3.39 - IDEF0 representation of the ‘procurement and development preparation’ process.



Source: Author production.

Specifically, this process should include the following tasks:

a. Support the finalization of procurement plans for subsequent phases as well as other documents necessary to buy the selected turnkey space segment solution;
b. Support the finalization of procurement or development plans for subsequent phases as well as other documents necessary to make or buy the ground segments;
c. Support the finalization of any other technical plan for subsequent phase (e.g. mission operations plan, verification plan).

In this process, it is recommended to have several iterations with manufacturers and developers to discuss and validate the plans. It should be highlighted that contracts and development agreements are recommended to be signed after the review and not in this process.

3.2.3.2.7 Space System Definition Review (SSDR)

This milestone represents a review of the most important outcomes that have been produced within this phase; specifically, the final space system implementation specifications (including the mission utility results that justify its selection) and the final procurement and development documents (including the final plans). This review should be performed by an external group of specialists with the appropriate knowledge and experience to judge the content that has been produced in this phase. The systems engineering group should participate in the review to provide clarifications, assess recommendations (together with the relevant mission stakeholders), and implement recommendations when required.

The primary objectives of this milestone are:

a. Assess the final space system implementation requirements, which include the mission utility results that justify its selection; and the final procurement and development documents, which include the final plans;
b. Establish recommendations showing issues such as unidentified errors, incomplete information, inaccurate plans, possible upgrades, and potential actions;
c. If possible during the review, assess the implementation of some of the recommendations (together with the relevant mission stakeholders);
d. If possible during the review, implement some of the accepted recommendations.

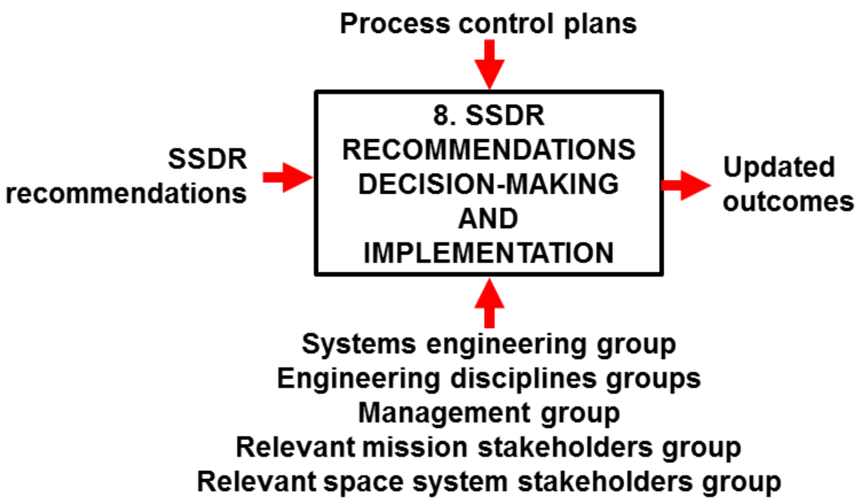
The idea of this review is to ensure that the segments systems constituting the space system are specified in detail, and thus, the procurement and development of such systems is ready to be initiated during the next phase.

3.2.3.2.8 SSDR recommendations decision-making and implementation

This process consists in assessing and implementing some of the recommendations that were produced during the SSDR but were not assessed or implemented during such review.

This process inputs the recommendations of the SSDR. At the end of this process, the systems engineering group should have update the outcomes of this phase with the accepted recommendations of the SSDR. Figure 3.40 illustrates the IDEF0 representation of this process.

Figure 3.40 - IDEF0 representation of the ‘SSDR recommendations decision-making and implementation’ process.



Source: Author production.

Specifically, this process should include the following tasks:

a. Assess the implementation of the recommendations that were not assessed during the SSDR (together with the relevant mission stakeholders);
b. Implement the accepted recommendations that were not implemented during the SSDR or those that were accepted in a.

3.2.3.2.9 End of phase and next phase start approval

This milestone represents the end of the current phase and the start of the next phase. The outcomes of the current phase should be approved and released. Then, the systems engineering group should be authorized to begin the effort of the next phase as a result of this milestone.

The primary objectives of this milestone are:

a. Obtain written approval from higher-level authorities to close the current phase;
b. Release the outcomes of this phase;
c. Obtain written notification from higher-level authorities about procurement contracts and development agreements signing;
d. Obtain written approval from higher-level authorities to begin the next phase and use the allocated resources during the following phase.

4 APPLICATION CASE

This chapter presents an application case that aims to illustrate briefly the application of the SPSYSE-TK methodology and the application of a traditional systems engineering methodology. Such applications enable the qualitative assessment of the SPSYSE-TK methodology with respect to a traditional systems engineering methodology in the subsequent chapter.

The ECSS systems engineering methodology was chosen as the traditional systems engineering methodology within this application case. It was selected for two main reasons. First, the methodology was established by important organizations in the space industry, such as ESA, CNES, and DLR, and it is widely recognized in several countries all over the world. Second, the ECSS methodology is described as a sequential approach, which is similar to the approach used to describe the methodology proposed in this work. Such approach of the ECSS systems engineering methodology is provided in the second version of its systems engineering standard, ECSS-E-10 Part 1B (ECSS, 2004). The subsequent version of this standard, the ECSS-E-ST-10C (ECSS, 2009b), which was the active[3] version during the development of this work, only provides requirements related to the systems engineering effort instead of descriptive information about the methodology as done in the version ECSS-E-10 Part 1B.

It should be highlighted that it is not easy to simulate the reality of a space project, which involves several stakeholders with different needs. Consequently, within this application case, the author intended to represent possible definitions, decisions, and ideas that the organizations and groups participating in the space project (e.g. customer, other stakeholders, systems engineering

[3] A newer version was released on February 2017 by the ECSS. This new standard, the ECSS-E-ST-10C Rev.1, also provides only requirements related to the systems engineering effort instead of descriptive information about the methodology as done in the version ECSS-E-10 Part 1B.

group, satellite manufacturers, and ground segment engineering group) might have in a real application. The idea was to represent different alternatives, circumstances, and ramifications that might have occurred. It should be noticed that values, features, ideas, concepts, and alternatives that are presented in this chapter were established mainly to illustrate the application of the ECSS and the SPSYSE-TK methodologies, and consequently, they might be different and much more complex in a real application. Furthermore, they might exhibit some conflict with real characteristics of the systems herein mentioned.

It should also be highlighted that within this application case, the Brazilian Ministry of the Environment is considered as the customer organization that contracts the systems engineering group for specifying a space system that fits best to its existing needs. The systems engineering group is who implements the ECSS and the SPSYSE-TK methodologies. The systems engineering group has the freedom of releasing RFIs, RFPs, and procuring turnkey satellites. Since this application case is illustrative, it was decided to not consider the existing limitations by public organizations in Brazil for executing contracts with prime contractors. Consequently, the Brazilian Ministry of the Environment although is a Brazilian public organization was considered to have freedom of contracting the systems engineering group as a prime contractor without considering any restriction regarding to procurement and contracting processes.

Following section contains a description of a mission in which the application of both the SPSYSE-TK and the ECSS methodologies relies on. Then, the following two sections describe the application of both methodologies within the scope of this work and in the context of such particular mission.

4.1 **Mission description**

The mission herein described is a hypothetical remote sensing mission that intends to detect illegal deforestation in the Brazilian Legal Amazon rainforest. Figure 4.1 illustrates the boundaries of Brazilian Legal Amazon rainforest.

Figure 4.1 - Brazilian Legal Amazon rainforest.

Source: Author production.

A remote sensing mission was chosen since quite a few turnkey satellites of this type are offered on the market from diverse manufacturers, such as Surrey Satellite Technology Ltd. (SSTL), Korea Aerospace Research Institute (KARI), Yuzhnoye, and Orbital ATK. Moreover, part of the specifications of such satellites is publicly available on the Internet. 'Attachment A - catalog of remote sensing turnkey satellites' shows a catalog of some turnkey satellites offered on the market and some of their specifications.

It is assumed that the mission is called Amazon Rainforest Deforestation Surveillance Mission (ARD-SM) and as stated previously the customer organization is a team of the Brazilian Ministry of the Environment. The mission aims to support the use of existing Brazilian deforestation monitoring systems, which currently use images coming from international satellites. Consequently, the ARD-SM targets to make available to such existing systems a particular satellite that can be managed as required by the Ministry of the Environment instead of being in control by international organizations. It is assumed that the Brazilian Ministry of the Environment has stated the following mission statement:

"The objective of the ARD-SM is to monitor the Amazon rainforest in order to identify any attempt of deforestation.

Specifically, the mission shall:

- Monitor regularly the Brazilian Legal Amazon rainforest;
- Identify any attempt of deforestation within the Brazilian Legal Amazon rainforest and notify to the Ministry of the Environment in less than 6 days from the time that the image was taken;
- Be compatible with at least one of the Brazilian National Institute for Space Research's (INPE) deforestation monitoring system, i.e. the Legal Amazon Deforesting Monitoring Project (PRODES) or the Real Time Deforesting Detection (DETER).

It is desirable for the mission to:

- Be compatible with both INPE's deforestation monitoring systems (i.e. PRODES and DETER systems);
- Use the Brazilian Microsatellites Launch Vehicle (VLM) to launch the satellite(s) of the system;

The mission shall be developed within the following constraints:

- The overall cost shall be less than M$100;
- The mission shall operate routinely before January 1, 2022 (preferably, before January 1, 2021);
- The mission shall last at least 4 years (preferably, 5 years)."

The Real Time Deforesting Detection (DETER) and the Legal Amazon Deforesting Monitoring Project (PRODES) are systems created by presidential decree for the reduction of the rates of deforestation of the legal Amazon in Brazil. Both systems belong to the Brazilian National Institute for Space Research (INPE) and were conceived to meet different but complementary objectives. (INPE, 2008, 2014)

The DETER system is a deforestation monitoring project developed by INPE for producing quick alerts related to changes in the forest cover of the Amazon rainforest. It was developed as an alert system for support the control of illegal deforestation and forest degradation. The DETER system can identify changes in the forest cover by clear cutting, forest degradation, and forest fire traces. It allows the detection of changes in the forest cover in areas larger than 0.25 km^2. The DETER system uses satellite images on a daily basis. Those images are processed to produce deforestation alert maps in 1 to 5 days that are delivered to deforestation control agencies. The DETER system was measured to have a reliability of its alerts of 94%. (INPE, 2008, 2014)

Similarly, the PRODES system is a deforestation monitoring project developed by INPE for producing annual rates of deforested areas. Annual rates are estimated from the increase of the size of deforested areas, which are identified from satellite images. The PRODES system uses images that are obtained approximately every 16 days and it measures deforestation by clear cutting. The PRODES system detects the increase of deforested areas when the deforestation is higher than 0.0625 km^2. It is more detailed than DETER system and it depends more on climatic conditions to obtain images without clouds; thus, it distributes deforestation results only once per year. (INPE, 2008, 2016)

It is assumed within this application case that the INPE's deforestation monitoring systems (i.e. DETER and PRODES) are completely independent systems and that the characteristics of the images that each one requires are very different. Consequently, a unique satellite cannot provide images for both application segment systems. It is also assumed that the reception of images by DETER and PRODES systems is accomplished using existing ground stations that are owned by INPE from CBERS and Landsat programs since neither of both deforestation monitoring systems have particular ground stations. CBERS and Landsat ground stations and associated networks are assumed to make available the images to the several Brazilian application systems, including the DETER and PRODES systems.

As a summary, the space system will be composed by two ground segments and a space segment within this application case. The ground segments are the ground application segment and the ground control segment. The ground application segment already exists and as stated in the mission statement will be either the DETER, the PRODES, or both deforestation monitoring systems and the reception ground stations and networks from CBERS and Landsat programs. On the other hand, the ground control segment will be developed. Finally, in accordance with the scope of this work, the space segment will be composed of turnkey satellites.

4.2 Application of SPSYSE-TK methodology

4.2.1 Phase 1: preliminary mission definition

4.2.1.1 Project kick-off

For the ARD-SM, this milestone might consist in a meeting among the organizations and groups participating in the project to formalize the initiation of the ARD-SM project.

4.2.1.2 Customer’s needs analysis

For the ARD-SM, task a. might consist in analyzing the needs declared by the Ministry of the Environment to answer several issues, such as the following:

- What are the boundaries of the Brazilian Legal Amazon rainforest?

- What is the typical area of deforested regions?
- What is the type of deforestations techniques that the Ministry of the Environment wants to identify (e.g. by cut or by burning)?
- What level of deforestation the Ministry of the Environment wants to identify (e.g. shallow cut or forest degradation)?
- How much time typically does it takes to deforest an area?
- How much frequent the satellite should revisit the Amazon rainforest?
- Is the 6-days response time enough for taking control actions?
- Are 6 days enough for the satellite send the image to the ground application segment, the ground application segment process the image, and deliver a notification to the Ministry of the Environment?
- Why the Ministry of the Environment wants to use a deforestation monitoring system already existing at INPE?
- How do the existing deforestation monitoring systems work?
- What is the status of the VLM?
- What are the characteristics of the VLM?

For the ARD-SM, task b., which can be performed simultaneously to the task a., might consist in reviewing previous reports that the Ministry of the Environment and other private environmental organizations and groups have issued about deforestation in the Amazon rainforest. Such reports might contain additional information that can aid in the identification of additional needs. It will be assumed that reports showed that the last systems that the Ministry of the Environment had tried to implement to fight against deforestation failed. Consequently, a need for succeeding emerges during this task.

Tasks c. would consist in identifying ambiguous or inconsistent needs. Ambiguous needs are those that may be interpreted in more than one way. Inconsistent needs are those that have a conflict with another. An ambiguous need, for instance, would be the following:

- Monitor regularly the Brazilian Legal Amazon rainforest;

What does the customer intend to say by monitoring ‘regularly’ the Amazon rainforest? Would ‘regularly’ mean an exact number of days? Does the customer know that value? Does the customer have at least an estimation of such value?

Similarly, an inconsistent need would be the following:

- Be compatible with both INPE’s deforestation monitoring systems (i.e. PRODES and DETER systems);

Is the customer aware that both systems operate in very different way? Is the customer aware that the PRODES system is used to measure the annual rate of deforested areas while the DETER system detects deforestation in real time?

Another inconsistent need (that emerged during task b.) would be that the customer needs the mission to succeed but at the same time, it intends to use a launch vehicle that is still in development. Is the customer aware of the risks involved?

Task d. would consist in resolving ambiguous or inconsistent needs together with the customer. It will be assumed that the customer replied that ‘regularly’ means at least in three days for the exemplified ambiguous need. It will be also assumed that the customer replied that it was aware of the inconsistency of the use of both deforestation monitoring systems and because of that is that it placed as a desirable aspect rather than mandatory. Consequently, the customer asks for keeping such need within the analysis. Finally, it will be assumed that the customer agreed that the use of the VLM was too risky, and consequently, it states to not consider it in further analysis.

4.2.1.3 Mission stakeholders analysis

For the ARD-SM, task a. might have resulted in the identification of the following mission stakeholders:

- Ministry of the Environment (it is the customer of the systems engineering group and the sponsor of the mission);
- Deforestation groups (they are the groups that execute deforestation practices);
- INPE (it is providing their deforestation systems);
- PRODES system team (it may be the responsible for detecting deforestation);
- DETER system team (it may be the responsible for detecting deforestation);
- Brazilian government (it is the government of the country where the mission will be implemented);
- Brazilian media (they are concerned on news);
- Brazilian environmental organizations and groups (they are concerned with the health of the Brazilian environment);
- International environmental organizations and groups (they are concerned with the health of the Brazilian environment).

Tasks b. and c. would consist in defining which stakeholders are relevant and their ranking. It will be assumed that the Ministry of the Environment, the deforestation groups, the INPE, the PRODES and DETER teams, and the Brazilian government were defined as the relevant stakeholders. They were also ranked in the order in which they were listed.

4.2.1.4 Mission stakeholders' needs analysis

Tasks a. and b. would consist in eliciting and reviewing the needs of the relevant mission stakeholders. Since the customer's needs were already elicited and reviewed in the first process of this phase, this process would be related to the needs of the other relevant stakeholders. For the ARD-SM, for instance, INPE might have declared that it wants to keep their deforestation monitoring systems operating as currently, so it would not allow changes in their systems (e.g. software, hardware, operation procedures).

For the ARD-SM, deforestation groups, which were established as relevant stakeholders, would be a source of several implicit needs. Then, task c. might consist in reviewing the most common deforestation practices (e.g. quick burning, slash-and-burn, cutting, clear cutting), which might result into additional needs.

Tasks d. and e. would be similar to the tasks b. and c. of the process '4.2.1.2 Customer's needs analysis' that was already described. Consequently, they are not going to be exemplified.

Task f. would consist in classifying (together with the most relevant stakeholders) the up-to-this-point refined needs into three categories: essential, conditional, and optional. Essential would be those that will determine the ARD-SM success, so they must be met. Conditional would be those that would be desirable to be met, but will not determine the ARD-SM success. Optional would be those that will not be addressed by the current mission but want to be registered for future missions. Finally, task g. would consist in ranking the conditional needs. Table 4.1 shows how the output of these tasks might look.

Table 4.1 - Classification of needs for the ARD-SM.

	Rank	Need
Essentials	-	Compatibility with at least one of the INPE's deforestation monitoring systems: the Legal Amazon Deforesting Monitoring Project (PRODES) or the Real Time Deforesting Detection (DETER)
	-	Monitor the Brazilian Legal Amazon rainforest at least every 3 days
	-	Notify to the Ministry of the Environment deforestation actions in less than 6 days from the time that the image was taken
	-	Detect deforested areas of at least 0.25 km^2
	-	The overall mission cost shall be less than M$100 (from the concept to the disposal)
	-	The mission shall operate routinely before January 1, 2022
	-	The mission shall last at least 4 years
	-	Obtain images in the whole visible spectrum and in the red and green bands
	-	Not change the PRODES system for the mission (e.g. procedures, staff, hardware, software)
	-	Not change DETER system for the mission (e.g. procedures, staff, hardware, software)
	-	The mission is expected to have higher chances of succeed
Conditional	1	The mission shall last at least 5 years
	2	The mission shall operate routinely before January 1, 2021
	3	Be compatible with both the PRODES and the DETER system
	4	Obtain images in the blue band
	5	Obtain images in the NIR band
Optional	-	Obtain images in the IR band

Source: Author production.

4.2.1.5 Mission goals definition

For the ARD-SM, task a. might have defined that the fulfillment of the essential need 'obtain images in the whole visible spectrum and in the red and green bands' will be determined by the spectral bands that would be sensed. In this case, the wavelengths of such bands would be the technical measures.

Task b. would determine what would be the minimum success criteria for such measures. In this case, the minimum success criteria might have been defined to be sensing at least within the following wavelengths:

- Band #1 (green): 520-590 nm;
- Band #2 (red): 620-680 nm;
- Band #3 (visible): 510-850 nm.

Task c. might have resulted in translating the aforementioned needs into mission requirements. Consequently, this task might have resulted into the following 'shall' statements:

- The ARD-SM shall provide images that correspond to the 520-590 nm spectral band (green);
- The ARD-SM shall provide images that correspond to the 620-680 nm spectral band (red);
- The ARD-SM shall provide images that correspond to the 510-850 nm spectral band (visible).

In a similar way, tasks d. and e. might have defined that the conditional needs 'obtain images in the blue band' and 'obtain images in the NIR band' will be determined by the capacity of sensing energy in the 450-510 nm and the 800-880 nm spectral bands, respectively. In this case, task e. might have resulted in translating such needs into conditional demands, which might look as the following 'should' statements:

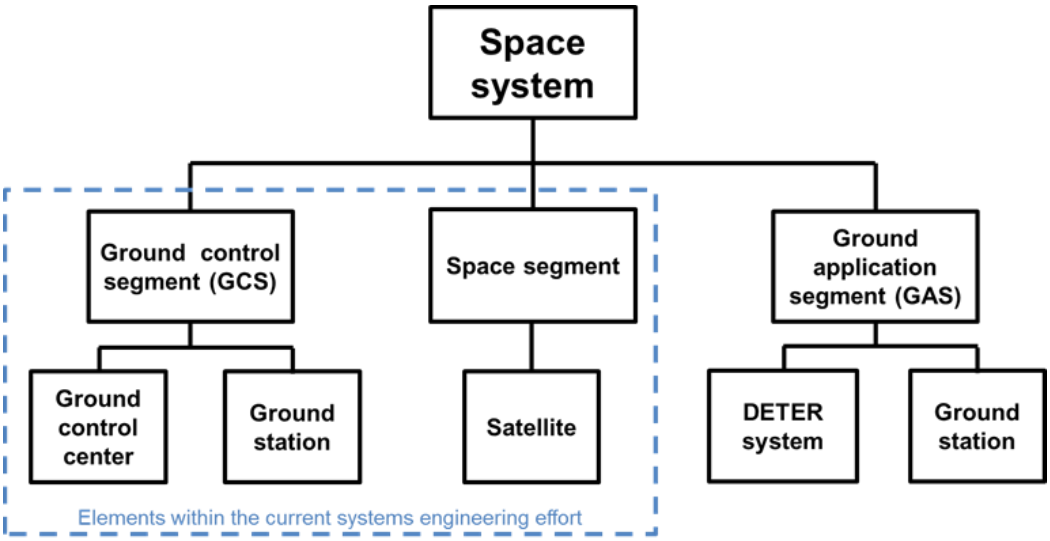
- The ARD-SM should provide images that correspond to the 450-510 nm spectral band (blue);
- The ARD-SM should provide images that correspond to the 800-880 nm spectral band (NIR).

4.2.1.6 Space system operational concepts and architectures development

For the ARD-SM, task a. might consist in reviewing how currently the Ministry of the Environment as well as other organizations and groups detect deforestation. This task might have resulted in the identification of a similar mission that already exists, the Deforestation Impact Estimation Project (DEIMES), which targets to obtain information about the environmental impact caused by deforestation and how it evolves over time (GORDON WOOD, 2016). If the use of the PRODES or DETER deforestation monitoring systems would not be indicated by the Ministry of the Environment, this task might have led to discover such systems and assessing if they could be used as part of the space system.

Task b and c. would define the major elements that will constitute the space system and which of them shall be specified within the current systems engineering effort. Figure 4.2 shows the first space system concept (i.e. space system concept #1) that might have resulted of such tasks for the ARD-SM.

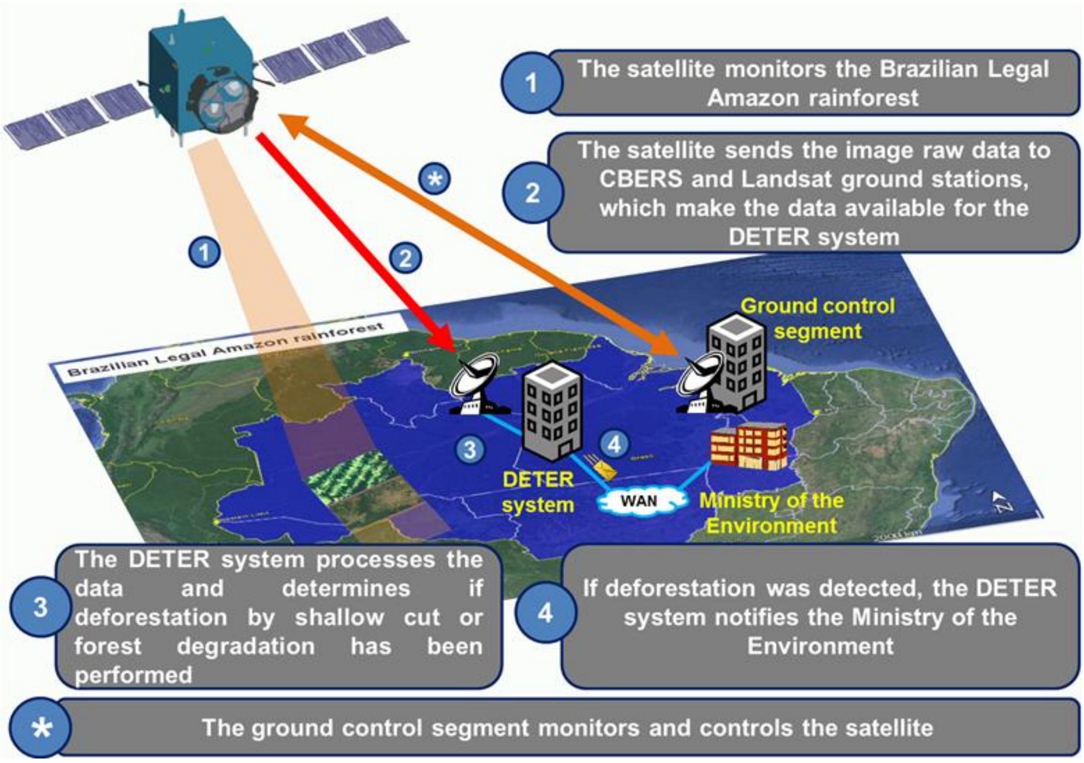
Figure 4.2 - Architecture for the space system concept #1 of the ARD-SM.



Source: Author production.

With such architecture of the space system, task d. would define representative operational scenarios of the system. An operational scenario for the ARD-SM might be the satellite detecting deforestation. In this scenario, the satellite might be orbiting in a sun-synchronous orbit. Then, as soon as the satellite is over the Amazon rainforest, it powers on its payload and starts taking images. Such images are sent to the ground application segment. The CBERS and Landsat program ground stations and networks make available the images to the DETER system, which processes them and tries to detect any deforestation action that might have been occurring or might have occurred recently. Then, if detected, the DETER system notifies to the Ministry of the Environment the coordinates in which deforestation was detected. This notification might be performed by email using the Wide Area Network (WAN) that the Ministry of the Environment and the INPE already have. The period between the time in which the image was taken and the notification to the Ministry of the Environment is less than 6 days as it was required. Figure 4.3 and Figure 4.4 illustrate characteristics of such operational concept.

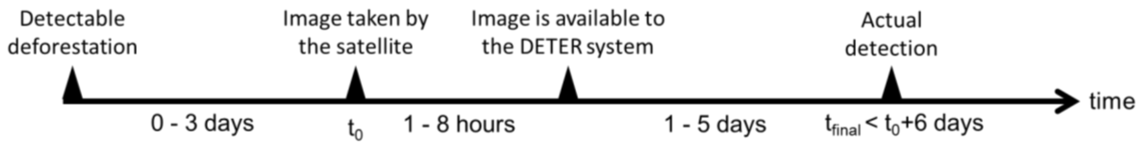
Figure 4.3 - Operational concept for the space system concept #1 of the ARD-SM.



The location of elements within Brazil are merely illustrative.

Source: Author production.

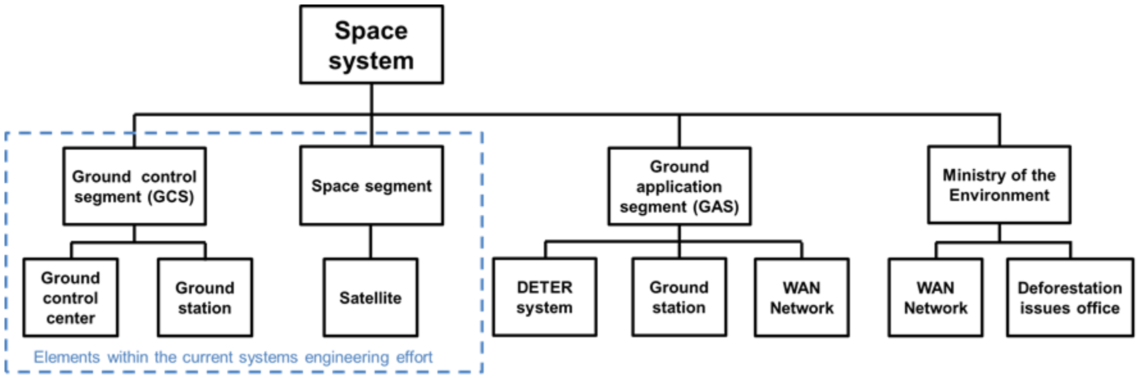
Figure 4.4 - Timeline for the space system concept#1 of the ARD-SM.



Source: Author production.

For the ARD-SM, task e. might have resulted in the refinement of the space system architecture as Figure 4.5 shows.

Figure 4.5 - Refined architecture for the space system concept #1 of the ARD-SM.



Source: Author production.

Finally, task f. would consist in defining alternative space system operational concepts and architectures (i.e. space system concept alternatives). Other space system concepts might be the following:

- Space system concept #2: one satellite in sun-synchronous orbit, a ground control segment, and the application segment using the already existing PRODES system;
- Space system concept #3: two satellites (both at sun-synchronous orbit), a ground control center that controls both satellites, and the ground application segment using the DETER and PRODES systems (being each system only compatible with the data of one of the satellites).

4.2.1.7 Space system requirements and conditional demands definition

For the ARD-SM, task a. would consist in reviewing the mission requirements and conditional demands to identify required and desired characteristics for each of the major elements that were previously recognized in the space system concept #1. For instance, a mission requirement stating ‘the ARD-SM shall monitor the Brazilian Legal Amazon rainforest at least every 3 days’ might be associated to the satellite. This might have resulted in the identification of an orbit requirement for the satellite requiring it to have a revisit period of at least 3 days. Similarly, the mission requirement stating that ‘the ARD-SM shall provide images that correspond to the 450-510 nm spectral band (visible)’ might have resulted in a requirement for the satellite to have a panchromatic camera sensing in such spectral band. On the other hand, the conditional demand ‘the ARD-SM should provide images that correspond to the 800-880 nm spectral band (NIR)’ might have resulted in the identification that it would be desirable if the satellite have a multispectral camera that includes such spectral band.

Task b. might have resulted in recognizing that the satellite requires two communication channels: one to send images to the ground application segment and the other to exchange telecommand and telemetry data with the ground control segment. Furthermore, task b. might have resulted in identifying that the satellite requires two operational modes. In the first mode with the satellite pointing its payload to nadir, the payload camera would be powered on when the satellite is over the Brazilian Legal Amazon rainforest. This might be the nominal operation mode. In the second mode, the satellite might be programmed via telecommand to point its payload to specific areas of the Amazon rainforest, which might be indicated by the Ministry of the Environment during the mission. After analysis of this second mode, it might be found that the satellite requires having roll maneuvers-capability; however, such maneuvers should ensure that the field of view of the antenna is still covering the ground station of the ground application system. Otherwise, real-time transmission might not be possible all the time, so an additional storage capability would be needed.

Other required or desired characteristics might be related to deforested areas characteristics (e.g. spatial resolution, swath), monitoring aspects (e.g. revisit time, latitudes that shall be covered), or to interfaces with the existing systems (e.g. INPE monitoring systems).

Tasks from c. to g. would be similar to the tasks from a. to e. of the process ‘4.2.1.5 Mission goals definition’ that was already described. Consequently, they are not going to be exemplified.

A short example of some space system requirements and conditional demands that might have been produced at this point could be the following:

General requirements

SPACESYSREQ-1. The space system cost shall be less than M$95;

SPACESYSREQ-2. The space system shall be in routinely mission operations no later than the January 1, 2022;

SPACESYSREQ-3. The space system shall determine the location of deforested areas detected after image processing with a geolocation accuracy of less than 500 m;

SPACESYSREQ-4. The satellite shall detect deforested areas of at least 0.25 km2;

SPACESYSREQ-5. The space system shall not cause any change in the DETER system (e.g. procedures, staff, hardware, software);

SPACESYSREQ-6. The uplink and downlink (telecommand and telemetry) communications shall be performed in S-band, with a data rate able to handle all necessary TM/TC for housekeeping operations;

SPACESYSREQ-7. Payload data downlink shall be performed in X-band;

SPACESYSREQ-8. The transmission of the TM/TC data to the ground control segment shall be completed in less than 1 day (TBC) after the end of a communication slot with the satellite;

SPACESYSREQ-9. The transmission of the payload data to the ground application segment shall be performed in real-time during the images acquisition.

Space segment (satellite) requirements

SPACESYSREQ-10. The satellite shall revisit any location of the Brazilian Legal Amazon rainforest at least every 3 days;

SPACESYSREQ-11. The satellite shall have at any band a spatial resolution better than 50 meters;

SPACESYSREQ-12. The satellite shall have a lifetime of at least 4 years;

SPACESYSREQ-13. The satellite shall take images that correspond to the 520-590 nm spectral band (green);

SPACESYSREQ-14. The satellite shall take images that correspond to the 620-680 nm spectral band (red);

SPACESYSREQ-15. The satellite shall take images that correspond to the 510-850 nm spectral band (visible);

SPACESYSREQ-16. The satellite shall record telemetry (TM) data on-board in a continuous way. The mass memory capacity shall be sized to record TBD days of mission before rollover;

SPACESYSREQ-17. The system design shall be compatible with a daily telemetry volume of TBD Gbit/day;

SPACESYSREQ-18. Payload output raw data shall be delivered in the appropriate format compliant to the ground application segment.

SPACESYSREQ-19. The satellite shall send telemetry data to the ground control segment at 2.7 GHz;

SPACESYSREQ-20. The satellite shall receive telecommand data from the ground control segment at 3.1 GHz;

SPACESYSREQ-21. The satellite shall send payload data to the ground control segment at 8.2 GHz.

Ground control segment requirements

SPACESYSREQ-22. The ground control segment shall monitor and control the satellite;

SPACESYSREQ-23. The space system shall update the on-board mission operations plan in conformity when required by the Ministry of the Environment or the ground application segment;

SPACESYSREQ-24. The ground control segment shall receive telemetry data from the satellite at 2.7 GHz;

SPACESYSREQ-25. The ground control segment shall send telecommand data to the satellite at 3.1 GHz;

SPACESYSREQ-26. The ground control segment shall generate and validate the telecommand (TC) before send them to the satellite;

SPACESYSREQ-27. The ground control segment shall perform systematic checks on the instrument performances;

SPACESYSREQ-28. The ground control segment shall perform instrument calibration and optimization.

General conditional demands

SPACESYSCOND-1. The space system might be in routinely mission operations no later than the January 1, 2021.

Space segment (satellite) conditional demands

SPACESYSCOND-2. The satellite might have a lifetime of at least 5 years;

SPACESYSCOND-3. The satellite should take images that correspond to the 450-510 nm spectral band (blue);

SPACESYSCOND-4. The satellite should take images that correspond to the 800-880 nm spectral band (NIR).

Finally, for the ARD-SM, task h. would consist in repeating previous tasks for the other space system concept alternatives.

4.2.1.8 Space system technical and programmatic plans development

For the ARD-SM, task a. would define a systems engineering plan for the space system concept #1. The systems engineering plan would cover the subsequent phases of the project, but with emphasis on the following phase. The systems engineering plan, at least for the following development phases (i.e. phases 2 and 3), should be in conformity with the phases and processes proposed in chapter '3 SPSYSE: the proposed methodology'.

Task b. might result in the identification of other plans. For the ARD-SM, this task might have resulted in the identification of the Request For Information (RFI) distribution plan. Then, task c. would consist in supporting the management group to define such plan for the following phase.

Now that the space system have been initially defined as well as the initial plans for its development, task d. would allow to estimate some programmatic aspects for the space system concept #1. It will be assumed that the cost and schedule of such alternative were estimated as a result of this task. Since the focus of this phase is more related to the definition of mission goals rather than to the space system definition, such estimations might have been performed using public information on the Internet about turnkey satellites as well as reports, papers, and books of previous similar missions.

Finally, task e. would consist in repeating previous tasks for the other space system concept alternatives.

4.2.1.9 Feasibility and utility evaluation

For the ARD-SM, task a. would consist in assessing the technical feasibility of the space system concept #1. Since the focus of this phase is more related to the definition of mission goals rather than to the space system definition, such assessment might have been performed using public information on the Internet about turnkey satellites as well as reports, papers, and books of previous similar missions. It will be assumed that after repeating this task for the three space system concepts (task c.), the three alternatives demonstrated that are technically feasible since similar space systems already exist and none of them involve any technological challenge.

Task b. would consist in assessing the programmatic feasibility of the space system concept #1 based on the programmatic aspects gathered in the previous process. It will be assumed that after repeating this task for the three space system concepts (task c.), the space system concept #1 and the space system concept #2 exhibited schedules and costs within the mission requirements. However, the space system concept #3 presented costs that are very likely to exceed the mission requirement related to cost.

According to previous results, task d. might have resulted in the disposal of the space system concept #3.

For task e. it will be assumed that the mission utility was defined together with the relevant mission stakeholders to be based on the capacity of the space system to detect deforestation in real time and the overall cost of such alternative. Then, weighting factors were given to such aspects (e.g. a weighting factor of 10 to the capacity of detecting deforestation in real time and a weighting factor of 5 to the cost of the alternative).

This assessment might have resulted in a numerical comparison among the alternatives that in a simplified way might look as Table 4.2 shows. It will be assumed that 10-points meant fully-compliancy and 0-points meant no-compliancy.

Table 4.2 - Space system concept alternatives comparison.

	Alternative#1	Alternative#2
Real-time detection capacity (x10)	10	6
Cost (x5)	7	10
TOTAL	135	110

Source: Author production.

It will be assumed, that even when the space system concept #1 provides a higher value of utility, both alternatives are selected to advance to the following phase (task f.). This might be the case since the information gathered up to this point about both concepts would not be much accurate. If the space system concept #3 had exhibited programmatic feasibility in task b., such concept might have been selected for advancing to the next phase and the space system concept #2 might have been discarded instead.

4.2.1.10 Preliminary Mission Definition Review (PMDR)

For the ARD-SM, this milestone might consist in a review made by an experienced group of specialists. It is assumed that they provide some recommendations. Some of them were assessed, accepted, and implemented by the organizations and groups participating in the project during the review. Some outcomes of this phase might have been updated according to those implemented recommendations. Other recommendations were kept in pending status to be further reviewed.

4.2.1.11 PMDR recommendations decision-making and implementation

For the ARD-SM, the tasks of this process might have resulted in the implementation of other recommendations that did not give time to implement during the review. Consequently, other outcomes of this phase might have been updated.

4.2.1.12 End of phase and next start approval

For the ARD-SM, this milestone might have consisted in a meeting to present and release the results of this phase to the other organizations and groups participating in the project. At the end of the meeting, a written approval might have been issued among participants to authorize the beginning of phase 2.

4.2.2 **Phase 2: mission and preliminary space system definition**

4.2.2.1 Space system stakeholders analysis

The application of this process for the ARD-SM would be similar to the one described previously in section '3.2.1.2.3 Mission stakeholders analysis'. However, the focus within this process is on relevant space system stakeholders instead of mission stakeholders. Consequently, this process might have resulted in the identification and ranking of the following space system stakeholders:

For the space system concept #1 of the ARD-SM, tasks a., b. and c. might have resulted in the identification and ranking of the following space system stakeholders:

1. Ministry of the Environment (it will be the owner of the space system);
2. INPE (it is the owner and the operator of the ground application system);
3. Turnkey satellites manufacturers (they are who may sell the satellite and deliver it in orbit ready for operating);
4. Ground control segment engineering group (it will be responsible for developing and operating the ground control segment);
5. DETER system team (it is the team that process images in the ground application segment);
6. Brazilian Space Agency (AEB) (it is the regulatory agency for the space activities in Brazil);
7. Brazilian Agency of Telecommunications Agency (ANATEL) (it is the regulatory agency for telecommunication services in Brazil);
8. International Telecommunications Union (ITU) (it is the regulatory agency for telecommunication services in the world).

Then, task d. would have repeated previous tasks for the space system concept #2.

4.2.2.2 Space system stakeholders' needs analysis

The application of this process for the ARD-SM would be similar to the one described previously in section '4.2.1.4 Mission stakeholders' needs analysis'. However, the focus within this process is on the needs of the space system stakeholders instead of the needs of the mission stakeholders. It is possible that some needs were actually identified during the previous phase. However, new needs might appear during this process. For instance, for the space system concept #1 this process might have resulted in the identification of a new need for both space system concepts elicited from AEB stating that the space system shall be in conformity with all the local laws and international regulations about the use of the space. Another need that might have shown up during this process for both space system concept alternatives is that the requests for frequency allocation within ANATEL and ITU of the system are recommended to be issued with appropriate anticipation (at least 1 year in advance from the date that the system is expected to be operating).

For the ARD-SM, it will be assumed that no inconsistent needs were gathered.

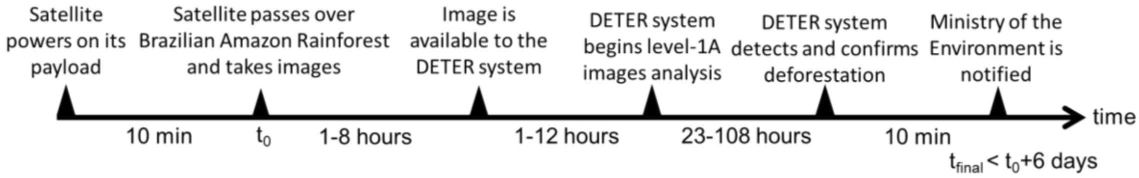
The previous tasks should be also applied for the space system concept #2.

4.2.2.3 Space system operational concepts and architectures refinement

For the space system concept #1 of the ARD-SM, the exemplified needs do not affect the space system operational concept and architecture of neither of the alternatives. However, it should be recalled that the focus during the first phase was to demonstrate that the mission requirements and conditional demands were realistic to be accomplished in technical and programmatic terms. Thus, the space system operational concepts and architectures might be lacking of some details. Then, during this process, such refinement of the space system operational concepts and architectures should be performed.

The refinement of the space system concept #1 might have included a refinement of the frequency that the satellite shall have for transmitting and receiving TM and TC (e.g. 2.7541 GHz for downlink and 3.1004 GHz for the uplink), or a refinement in the timeline that was shown in Figure 4.4, which now might look as Figure 4.6 shows.

Figure 4.6 - Refined timeline for the space system concept#1 of the ARD-SM.



Source: Author production.

The previous tasks should be also applied for the space system concept #2.

4.2.2.4 Space system requirements and conditional demands refinement

For the space system concept #1 of the ARD-SM, task a. might have resulted in the identification of a new requirement for the satellite powering on its payload 10 minutes before passing over the Amazon rainforest. Such requirement might have resulted in a required capacity for the satellite or for the ground control segment. If allocated to the satellite, the satellite would require identifying its position during its orbit and determining that 10 minutes later is going to pass over the Amazon rainforest. If allocated to the ground control segment, the control center would require to program via telecommand the time in which the payload is going to pass over the Amazon rainforest.

As occurred with the space system operational concepts and architectures, the space system requirements that were defined during the previous phase are likely to be missing several details. Then, during this process, the refinement of such requirements should be performed. This refinement should reveal new requirements and conditional demands. Similarly, it might result in the update some of the requirements and conditional demands that were previously discovered, such as spatial resolution, swath, revisit time, latitudes that shall be covered, interfaces, costs, spectral bands of the payload, preliminary characteristics of the orbit (e.g. semi-major axis, inclination, LTDN). For instance, this process might have clarified some cost aspects. Then, this might have resulted in the refinement of the cost allocation so the satellite might be limited now to a cost of M$45 with a margin of M$10, the ground station of the ground control segment to a cost of M$35 with a margin of M$5, and so on.

The previous tasks should be also applied for the space system concept #2.

4.2.2.5 Ground segments refinement

For the space system concept #1 of the ARD-SM, task a. of this process might have resulted in the identification of the frequency that the payload data shall be transmitted at. Since the ground application segment already exists, it would be a relevant source of non-negotiable requirements. Examples of such requirements might be:

- The data transmission equipment shall transmit data to the ground application segment at a central frequency of 8.2345 GHz;
- The data transmission equipment shall transmit data to the ground application segment with a bandwidth of 20 MHz;
- The data transmission equipment shall transmit data to the ground application segment at a minimum data rate of 100 Mbps.

Task b. would consist in changing the satellite requirements and conditional demands to be compliant with the non-negotiable requirements of the ground application segment.

Task c. would consist in repeating tasks a. and b. for the ground control segment. Then, task a. might have resulted in the identification of the location of its ground station as a driver feature. Depending on where it is, the orbit of the satellite, the antenna footprint, or the required Equivalent Isotropically Radiated Power (EIRP) might change. Then, task b. would harmonize such driver feature.

For instance, as an outcome of this process, the satellite might be required to have an EIRP higher than the initially conceived to avoid problems related to the location of the ground station, which it is assumed that it has not been defined yet.

The previous tasks should be also applied for the space system concept #2.

4.2.2.6 Space segment refinement and RFI preparation

For the space system concept #1 of the ARD-SM, task a. might refine the orbit characteristics and optical parameters. This refinement might have revealed requirements for attitude maneuvers of at least 30°, for pointing knowledge accuracy of less than 0.1°, and for attaching context information about the satellite orbit and attitude to any image taken.

Similarly to the previous process, task b. would consist on harmonizing together with the ground segments about the non-negotiable and driver characteristics. As it was stated, this might have resulted in allocating a high EIRP to the satellite to avoid problems related to the location of the ground station.

In task c., the satellite requirements and conditional demands would be established in order to be included within a Request For Information (RFI) document that will be distributed among several satellite manufacturers (tasks d. and e.). During the preparation of the RFI responses, some clarifications might have been given to the satellite manufacturers (task f.).

It will be assumed that in addition to the requirements and conditional demands for the satellite, the RFI asked for the manufacturers to include the maturity of their turnkey satellites, the flight experience, and preliminary costs and schedules. The RFI might have stated that only qualified satellites shall be included in the responses and that preliminary costs and schedules shall not differ with the future detailed proposals that will be gathered during the next phase in more than 10%. Consequently, only manufacturers replying to the RFI would be considered for future RFP.

The previous tasks should be also applied for the space system concept #2.

4.2.2.7 Space system integration analysis

It will be assumed that for the satellite of the for the space system concept #1 of the ARD-SM, three different manufacturers submitted proposals. Figure 4.7, Figure 4.8, and Figure 4.9 show a brief summary of some of the characteristics of each of the proposals:

Figure 4.7 - Satellite proposal #1: SICH-2M by Yuzhnoye.

YUZHNOYE design office

SICH-2M Satellite

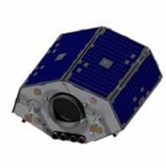
Payload Mass	206 kg
Satellite Mass	500 kg
Stabilization mode	3-axis with reaction wheels and magnetic torquers
Attitude	Attitude Control Accuracy: < 0,2 ° (while imaging) and < 5 ° (standby) Maneuver Capacity: ± 40 ° from nadir
Propulsion	Ammonia propulsion system
Communication	320 Mbps Data Rate
Orbit	Circular sun-synchronous (~97,4 ° inclination)
Designed Life	7 years
Onboard Data Storage Capability	2 TB
Spectral Bands	High Res.: 500-890 nm / MS: 500-590 nm (Green) / 610-680 nm (Red) / 690-790 nm (NIR) / 790-890 (NIR) / IR: 8000-10500 nm / 10500-11500 nm / 11500-12500 nm / 12500-13500 nm
GSD	High Res.: 1,9 m / MS: 5,7 m (at nadir) / IR: 110 m (at nadir)
Swath	High Res.: 68 km (at nadir) / MS: 64 km (at nadir) / IR: 68 km

Source: Adapted from Yuzhnoye (2015).

Figure 4.8 - Satellite proposal #2: SSTL-300.

SURREY SATELLITE TECHNOLOGY LTD

SSTL-300



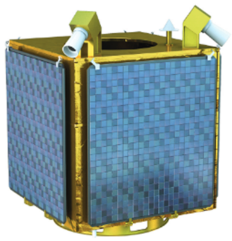
	SSTL-300 S1
Satellite Mass	350 kg
Communications	Encryption of all TM/TC links / Payload data encryption
Orbit	500 km, SSO, 10:30am LTAN
Designed Life	7 years
Spectral Bands	Blue, Red, Green, Near IR, Panchromatic
GSD	0,75 m (PAN) / 3 m (MS)
Swath	17 km
Digitisation	10 bits
SNR	All bands > 100:1
MTF	10% (at Nyquist)
Compression	JPEG-LS configurable
Revisit	Coverage/revisit 2 days worldwide
Delivery Schedule	24 months
Other features	Fast slew, 45° off-track pointing

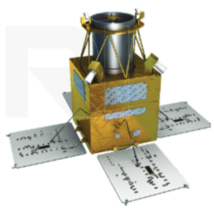
Source: Adapted from SSTL (2012).

Figure 4.9 - Satellite proposal #3: KSP-500B by KARI.

KARI Korea Aerospace Research Institute

KSP-500B Satellite





Payload Mass	123 kg
Payload Dimensions	1,2 m x 1,2 m x 0,4 m (H) (internal) / 1,3 m x 1,0 m x up to LV fairing limitation (external)
Payload Power	325 W (peak) / 100 W (average)
Platform Mass	330 kg (without propellant)
Platform Dimensions	1,4 m x 1,4 m x 1,6 m (H) (stowed) / 3,8 m x 3,8 m x 1,6 m (H) (deployed)
Platform Power	1000 W / Batteries: 45 Ah, Li-Ion / Main Bus: 50 V (unregulated)
Stabilization Mode	3-axis with reaction wheels and magnetic torquers
Attitude	Pointing Accuracy: 0,015 ° (3σ) / Pointing Stability: 0,004 °/s (3σ) / Pointing Agility: 1,0 °/s
Propulsion	30 kg Propellant Capacity / 1 N x 8 Thrusters / 37 L Hydrazine mono-propellant tank
Communication	320 Mbps X-Band Data Downlink / S-Band Telemetry and Telecommand Downlink-Uplink
OBDH	SpaceWire, UART, CAN, MIL-STD-1553B
Thermal	Primarily Passive Type
Orbit	LEO: 500-700 km
Designed Life	7 years
Data Storage Capability	256 Gb
Heritage	KOMPSAT series
Delivery Schedule	48 months
GSD	PAN: 1 m / MS: 4 m (@ 528 km)
Swath Width	> 15 km @ 528 km

Source: Adapted from KARI (2015).

Then, task a. would consist in reviewing the proposals to identify new potential characteristics for both the satellite and the ground control segment. It will be assumed that after the analysis of the proposals was identified that the requirement for attitude maneuvers of at least 30° and for pointing knowledge accuracy of less than 0.1° was very far of what can actually accomplished using turnkey satellites (task b.). Consequently, such requirements might be updated now to 40° and 0.05°, respectively (task c.). Another update might be related to the lifetime. It was initially stated as requirement a lifetime of 4 years and as conditional demand a lifetime of 5 years. Now that the RFIs showed that such aspect would be met, such requirement might be updated.

The previous tasks should be also applied for the space system concept #2.

4.2.2.8 Space system technical and programmatic plans refinement

The application of this process for the ARD-SM would be similar to the one described previously in section '4.2.1.8 Space system technical and programmatic plans development'.

For the space system concept #1 of the ARD-SM, this process would update the systems engineering plan and other plans that were produced in the previous phase in accordance with the more detailed definition about the space system and its elements that is had. The RFI distribution plan that was produced during previous phase was actually executed to distribute the RFI, so this plan would not require to be updated. However, during this process a Request For Proposal (RFP) distribution plan, a preliminary procurement plan, or a decision management plan for the next phase might be produced. The mission operations plan, if it was not defined during the previous phase, might be produced within this process.

Finally, this process would update the programmatic aspects of the space system concept #1 in accordance with the actual proposals that were received. It will be assumed that the cost, schedule, and risk of the space system concept #1 was estimated from the average cost, delivery schedule, and maturity levels of the three proposals received, respectively. Costs related to the ground control segment were also added, The delivery schedule of the ground control segment might be defined as a requirement for such segment in order to be less than the satellite's. Finally, the ground control segment is expected to not add any risk to the system. Now, a realistic estimation of the cost, schedule, and risk of the space system concept #1 is had.

The previous tasks should be also applied for the space system concept #2.

4.2.2.9 Feasibility and utility evaluation

The application of this process for the ARD-SM would be similar to the one described previously in section '4.2.1.9 Feasibility and utility evaluation'. It will be assumed that the technical and programmatic feasibility of both concepts was confirmed and that the characteristics of the concepts presented in Table 4.3 represent the main valuable aspects that the Ministry of the Environment defined to choose between the two concepts.

Table 4.3 - Space system concept alternatives comparison.

	Space system concept #1	Space system concept #2
Lifetime	7 years	6 years
Real-time detection capacity	Yes	Partial
NIR-band capacity	Yes	No
Delivery schedule	36 months	30 months

Source: Author production.

The Ministry of the Environment might also have assigned weighting factor to such aspects (e.g. 10 for lifetime, 8 for real-time detection, 6 for NIR-band capacity, and 4 for delivery schedule). This assessment might have resulted in a numerical comparison among the alternatives that might look as Table 4.4 shows. It will be assumed that 10-points meant fully-compliancy and 0-points meant no-compliancy.

Table 4.4 - Space system concept alternatives mission utility results.

	Concept#1	Concept#2
Lifetime (x10)	10	9
Real-time detection capacity (x8)	10	5
NIR-band capacity (x6)	8	0
Delivery schedule (x4)	6	10
TOTAL	252	170

Source: Author production.

4.2.2.10 Mission goals and space system operational concept and architecture baseline

For the ARD-SM, tasks a. and b. might result in the agreement of baselining the space system concept #1. Now, it has been set that the space system will be composed by one sun-synchronous satellite, the ground application segment using the DETER system, and a ground control segment. All of them with the preliminary characteristics that have been defined within the previous processes.

Tasks c. and d. would result in the redefinition and baseline of the mission goals (i.e. mission requirements and conditional demands). For instance, the required lifetime might be redefined to 6 years, or the previous conditional demand about having a NIR-spectral band might become a mission requirement instead (since the market showed that such capacity is feasible to implement and does not add too much cost).

At the end of this process, a document might be prepared with the baselined mission requirements and conditional demands as well as the baselined space system operational concept and architecture. An ID might be assigned to requirements and conditional demands to keep traceability with previous and later processes.

4.2.2.11 Mission and Preliminary Space System Definition Review (MPSSDR)

For the ARD-SM, this milestone may consist in a review made by an experienced group of specialists. It is assumed that they provide some recommendations. Some of them were assessed, accepted, and implemented by the organizations and groups participating in the project during the review. Some outcomes of this phase might have been updated according to those implemented recommendations. Other recommendations were kept in pending status to be further reviewed.

4.2.2.12 MPSSRD recommendations decision-making and implementation

For the ARD-SM, the tasks of this process might have resulted in the implementation of other recommendations that did not give time to implement during the review. Consequently, other outcomes of this phase might have been updated.

4.2.2.13 End of phase and next phase start approval

For the ARD-SM, this milestone might have consisted in a meeting to present and release the results of this phase to the other organizations and groups participating in the project. At the end of the meeting, a written approval might have been issued among participants to authorize the beginning of phase 3.

4.2.3 Phase 3: space system definition

4.2.3.1 Space segment refinement and RFP preparation

The application of this process for the ARD-SM would be similar to the one described previously in section '4.2.2.6 Space segment refinement and RFI preparation'. However, the focus within this process is to produce a RFP instead of a RFI. The RFP shall contain the detailed requirements and conditional demands for the satellite that will be procured. It should be highlighted that such requirements and conditional demands would be from a buyer-point of view. For instance, the focus will not be on asking for a satellite with an exact mass or with a power subsystem delivering a given amount of kilowatts. Instead, the focus will be on characteristics that the satellite shall have to meet mission requirements or that should preferably have to meet conditional demands. An example of such characteristics might be the minimum field of view, minimum focal length, minimum number or bandwidth of the spectral bands, EIRP, maneuver capacity, minimum delta-V capacity, capacity to survive at given orbit or within certain altitudes, minimum data rate at a given frequency, and the minimum capacity of on-board storage.

While the detailed requirements and conditional demands for the satellite are being prepared, there should be performed a parallel harmonization together with the ground control segment requirements in order to ensure compatibility between both segments.

4.2.3.2 Ground segments refinement

The application of this process for the ARD-SM would be similar to the one described previously in section ‘4.2.2.5 Ground segments refinement’. However, the focus within this process is to ensure that the requirements and conditional demands included in the satellite RFP are complete and thus the satellite will not present complications regarding with the ground control segment.

4.2.3.3 Space segment RFP responses analysis and ground segments refinement

For the ARD-SM, it will be assumed that the proposals from the previous phase were updated. Then, task a. would consist in reviewing the three proposals to recognize characteristics for the ground control segment. This might have resulted in a summary as Table 4.5 shows after different analyses (e.g. orbital analysis, payload parameters analysis) performed from the RFP responses.

Table 4.5 - Proposals detailed characteristics.

	Satellite proposal #1 (*)	Satellite proposal #2 (*)	Satellite proposal #3(*)
Focal length	860 mm	6670 mm	1320 mm
Field of View	7.94°	1.95°	1.63°
Radiometric resolution	10 bit	10 bit	10 bit
Panchromatic band	500-890 nm	450-650 nm	450-900
Multispectral bands	500-590 nm (green) 610-680 nm (red)	440-510 nm (blue) 510-590 nm (green) 600-670 nm (red)	450-520 nm (blue) 520-600 nm (green) 630-690nm (red)
NIR band	690-790 nm 790-890 nm	760-910 nm	760-900 nm
Maneuver capacity	40°	45°	45°
Data transmission rate	320 Mbps	105 Mbps	240 Mbps
Data memory	2 TB	16 GB	512 GB
Lifetime	7 years	7 years	7 years
Delivery schedule	36 months	24 months	52 months
Swath@ 634.36 km	88 km	21 km	18 km
GSD@634.36 km	7.4 m	1 m	5 m
Other capabilities	IR bands	Encryption	Stereo imaging

(*)Some of the previous parameters might differ from real parameters for the exemplified satellites. In a real application, the RFP responses shall contain the exact values of each proposal.

Source: Author production.

The review might have resulted in identifying that the ground control segment would require encryption/decryption capabilities in order to be compatible with the satellite proposal #2.

Once that new characteristics are identified, the ground control segment requirements might be delivered to the engineering discipline group that will be performing the lower level development of the ground control segment (task b.). Such organization, for instance might have proposed two ground control segment alternatives. One alternative compatible with the satellite proposals #1 and #3, and the other compatible with the satellite proposal #2 (since it includes encryption/decryption capabilities).

At the end of this process, there would be three space system implementation alternatives. Table 4.6 summarizes such alternatives in terms of the satellite and ground control segment proposals.

Table 4.6 - Space system implementation alternatives.

	Space system implementation #1	Space system implementation #2	Space system implementation #3
Satellite	Satellite proposal #1	Satellite proposal #2	Satellite proposal #3
Ground control segment (GCS)	GCS proposal #1	GCS proposal #2	GCS proposal #1
Ground application segment	DETER system and CBERS and Landsat ground stations		

Source: Author production.

4.2.3.4 Space system technical and programmatic plans refinement

The application of this process for the ARD-SM would be similar to the one described previously in section '4.2.2.8 Space system technical and programmatic plans refinement'.

For the space system implementation #1 of the ARD-SM, this process would update the systems engineering plan and other plans that were produced in the previous phase in accordance with the detailed definition about the space system and its elements that is had. The RFP distribution plan that was produced during previous phase was actually executed to distribute the RFP, so this plan would not require to be updated. During this process, the verification, operations, and procurement plan might be detailed.

Finally, this process would update the programmatic aspects of the space system implementation #1 in accordance with the final proposals that were received. Now, the cost, schedule, and risk of the space system implementation #1 was calculated from the real cost, delivery schedule, and risk measures of the satellite proposal #1 and the GCS proposal #1.

The previous tasks should be also applied for the space system implementations #2 and #3.

4.2.3.5 Space system implementation alternatives evaluation and baseline selection

For the ARD-SM, tasks a. and b. would consist in assessing the programmatic feasibility of the system implementation alternatives. It will be assumed that the space system implementation #1 and #2 demonstrate to be programmatically feasible. However, the space system implementation #3 showed a very tight schedule, which significantly increased the risks of deploying the space system before the January 1, 2022 as required by the Ministry of the Environment. Then, such alternative was discarded (task c.).

For task d., it will be assumed that the characteristics presented in Table 4.7 represent the main valuable aspects that the Ministry of the Environment defined to choose between the two space system implementation alternatives. It should be highlighted that the Ministry of the Environment might have chosen such aspects according to what adds more value to the mission. Such aspects are likely to be related with an enhanced fulfillment of a mission requirement or to the fulfillment of the conditional demands. In this case, it will be assumed that the Ministry of the Environment also assigned weighting factor to such aspects (e.g. 10 for revisit, 8 for delivery schedule, 4 for how useful the multispectral bands are, and 4 for the data transmission capacity). This assessment might have resulted in a numerical comparison among the alternatives that in might look as Table 4.7 shows. It will be assumed that 10-points meant fully-compliancy and 0-points meant no-compliancy.

Table 4.7 - Space system implementation alternatives mission utility results.

	Implementation#1	Implementation#2
Revisit (x10)	10	6
Delivery schedule (x8)	5	10
Multispectral bands (x6)	8	10
Data transmission capacity (x4)	10	6
TOTAL	228	224

Source: Author production.

Finally, task e. would consist in selecting the space system implementation #1. This would mean that the satellite proposal #1 and the ground control segment proposal #1 were selected. The satellite will be then procured from Yuzhnoye manufacturer and the ground control segment will be developed by the ground control segment engineering group that is also participating in the project.

4.2.3.6 Procurement and development preparation

For the ARD-SM, and now that the space system implementation was selected, this process might consist in several meetings with the turnkey satellite manufacturer as well as with the ground control segment developers to finalize some issues. Such issues might be for instance: how the production will be monitored, what clauses the contracts will include, and when they should have a product for testing the space system integration. Other meetings might be performed with the operations group to finalize the operations or any other related plan (e.g. support plan, disposal plan).

4.2.3.7 Space System Definition Review (SSDR)

For the ARD-SM, this milestone may consist in a review made by an experienced group of specialists. It is assumed that they provide some recommendations. Some of them were assessed, accepted, and implemented by the organizations and groups participating in the project during the review. Some outcomes of this phase might have been updated according to those implemented recommendations. Other recommendations were kept in pending status to be further reviewed.

4.2.3.8 SSRD recommendations decision-making and implementation

For the ARD-SM, the tasks of this process might have resulted in the implementation of other recommendations that did not give time to implement during the review. Consequently, other outcomes of this phase might have been updated.

4.2.3.9 End of phase and next phase start approval

For the ARD-SM, this milestone might have consisted in a meeting to present and release the results of this phase to the other organizations and groups participating in the project. At the end of the meeting, a written approval might have been issued among participants to authorize the beginning of the subsequent phases (e.g. production and monitoring).

4.3 Application of ECSS methodology

The application of the ECSS methodology in the context of the mission described in section '4.1 Mission description' is included at the end of this document in 'Attachment C - application of ECSS methodology'.

5 SPSYSE-TK METHODOLOGY ASSESSMENT

This chapter presents an assessment of the SPSYSE-TK methodology that this work proposes.

5.1 SPSYSE-TK methodology vs. previous findings

This section describes the assessment of the proposed methodology with respect to the relevant characteristics that a systems engineering approach that considers the use of commercial products should have according to the literature review. More details about the characteristics of the systems engineering approaches that consider the use of commercial products are in section ‘2.3 Systems engineering with the use of commercial products’.

The SPSYSE-TK methodology performs a top-down definition, which begins with the mission; then, passes to the space system- and segment-levels, and ends at the segment systems-level. While descending levels and adding details to them, the methodology incorporates a market analysis, which allow adjusting the definition of such levels accounting the bottom-up constraints imposed by the market alternatives. This logic, which combines top-down and bottom-up activities, in accordance with the literature review, makes the SPSYSE-TK methodology a systems engineering approach customized for accommodating commercial products, specifically turnkey satellites. The SPSYSE-TK methodology implements top-down activities, such as requirements decomposition and derivation and architecture definition, while implementing bottom-up activities (e.g. alternatives evaluation, selection, and negotiation) that enable conceiving the space system based on what is available and not only on what is required.

Some development approaches considering the use of commercial products that have been produced in other industries have established a two phases approach for defining a system. In the first phase, it is defined what is needed and what is available on the market. In the second phase, a refinement of what is needed is made in terms of market characteristics. The SPSYSE-TK methodology follows such logic. However, due to the complexity of space projects, the SPSYSE-TK methodology proposes three phases. The first for identifying needs. The second for identifying market preliminary market characteristics and refining the needs according to such characteristics. Finally, the third phase for recognizing detailed market characteristics and then performing a final refinement of the solution.

In more detail, the SPSYSE-TK methodology, as illustrated in Figure 3.4, works as a gear system. Needs drive mission goals; mission goals drive the space system definition; the space system definition drives a market analysis; market analysis drives the redefinition of mission goals; and so on. Such logic exhibits that the methodology herein proposed implies iteratively and constant trade-offs among what is required, what is available on the market, and the definition of the system. This characteristic is also typical in systems engineering approaches considering the procurement of commercial products according to the literature review.

A recommended characteristic for systems engineering efforts considering the use of commercial products is that they must allow the requirements to be sufficiently flexible to accommodate a variety of available commercial products. The SPSYSE-TK methodology allows such flexibility in two ways. First, the methodology embrace the use of the term ‘conditional demands’, which are related to needs that should preferably be met but not mandatorily. During the establishment of requirements and conditional demands, it is defined what is essential and what could be given up if needed. Then, conditional demands enable the accommodation of different products. Second, the methodology allows the evolution of requirements through the different phases. During the second phase, such evolution is based on real market information coming from the RFI responses. Moreover, during the third phase, such evolution is based on detailed information coming from the RFP responses of the space segment.

Another characteristic that is recommended for systems engineering efforts that consider the use of commercial products is that requirements must be first identified, and then, the market analysis should be performed. The SPSYSE-TK methodology possesses this feature through the use of requirements and conditional demands. Requirements and conditional demands not only enable the accommodation of different products as mentioned before, but also they ensure that the alternatives have a core of essential characteristics that are aligned with the needs. This helps to filter alternatives that would not address the minimum required. Otherwise, the solution space might be too wide and the fulfillment of some essential needs might be in risk when selecting among alternatives.

Systems engineering efforts that consider the use of commercial products should also involve knowing policies, regulations, and directives regarding the use of commercial products. The SPSYSE-TK methodology encourages the clarification of such matters when issuing the RFI and the RFP during phases 2 and 3.

In conformity with findings of other authors about systems engineering efforts that consider the use of commercial products, the SPSYSE-TK methodology includes activities that are commonly performed in traditional approaches. However, such activities differ from traditional approach in how, when, and with what market considerations they are performed. The SPSYSE-TK methodology includes feedbacks to traditional activities according to market-imposed characteristics. Then, the proposed methodology allows updating the outcomes of such traditional activities while solving integration issues that may occur due to the use of turnkey satellites.

The literature review also showed that systems engineering efforts that consider the use of commercial products should use well-known techniques for deriving requirements or selecting among alternatives. The SPSYSE-TK methodology allows flexibility regarding the use of techniques at any process since it describes what to do and not how to do it. For instance, a functional analysis can be implemented for identifying new requirements. Similarly, different techniques for establishing the operational concepts and architectures can be used. Furthermore, different techniques can be used for selecting among alternatives, such as multi-criteria decision-making, analytic hierarchy process (AHP), weighted scoring method (WSM), cost-versus-benefit studies, and utility analysis. It should be highlighted that even when the methodology is flexible about selection techniques, the SPSYSE-TK methodology encourages the selection of an alternative based on the utility that adds to the mission (i.e. mission utility). Mission utility is likely to depend mainly on the conditional demands.

The SPSYSE-TK methodology involves the stakeholders for the evaluation and selection among alternatives as some authors recommend for systems engineering approaches that consider the use of commercial products. This ensures that the stakeholders' interests are continually considered through all the phases of the methodology while reducing the number of candidate solutions.

The aforementioned facts demonstrate that the SPSYSE-TK methodology possesses the main features of a systems engineering effort that considers the use of commercial products, and therefore can be considered as it.

5.2 SPSYSE-TK methodology vs. ECSS methodology

This section describes an assessment of the proposed methodology with respect to a traditional systems engineering methodology. Specifically, the SPSYSE-TK methodology is assessed with respect to the ECSS systems engineering methodology. The assessment herein presented is qualitative and based on the application of both methodologies for a same problem in order to identify similarities and differences that the methodology has with respect to the traditional one. More details about the applications of the SPSYSE-TK methodology and the ECSS systems engineering methodology are in chapter '4 Application case'.

5.2.1 General differences and similarities

The SPSYSE-TK methodology, as seen in the application case, is capable of producing results as complete as the results that can be produced by a traditional systems engineering methodology, such as the ECSS methodology. Furthermore, the SPSYSE-TK methodology suggests adding new processes and tasks as well as changes in the sequence of the processes that are expected to ease and delineate the implementation of the systems engineering effort in specific projects that fits with the scope of this work (i.e. projects based on turnkey satellites procurement).

The following paragraphs describe issues of the ECSS methodology and how the SPSYSE-TK methodology is addressing them.

The ECSS systems engineering methodology is intended to lead the development of space systems and space products customized for a specific set of needs. This wide scope makes it general and its implementation to a certain extent become dependent on the project characteristics and the interpretation of who implements it. For instance, in the ECSS methodology it was hard for the author of this work to discern in some processes up to which levels of the space system hierarchy such processes would be applicable. In fact, the author while analyzing and applying the ECSS methodology in the application case had to stop several times and infer up to which level a process might be applicable. On the other hand, the SPSYSE-TK methodology that is proposed in this work points to the development of space systems and more specifically, to the development of space systems in which its space segment is constituted by turnkey satellites procured from the market. This specific application allows the SPSYSE-TK methodology to be more detailed and to be less dependent on the interpretation of who implements it.

During the ECSS methodology implementation, several processes demonstrated to be inappropriate and incompatible for the space projects within the scope of this work. This was the case especially when those processes referred to tasks that are typically performed during the development of new individual systems, such a satellite. For that incompatibility, such processes required a reinterpretation before applying them to the mission of the application case. In the SPSYSE-TK since the processes have been conceived for the particularities of the space projects within the scope of this work, those incompatibilities are avoided.

The ECSS methodology describes the relationship of its processes through documents that flow between them. Several of those documents flowing between processes have a similar content and the same document appears as input or output of several processes in different phases without specifying what of its content is applicable in such moment. Instead, the ECSS provides a description of the content of such document typically in its final version. This document-focused approach makes difficult to identify what exactly is flowing between processes, and consequently, it could make difficult the implementation of such methodology by different organizations or groups. The SPSYSE-TK methodology is focused on the essential contents that a process should produce instead. This is expected to ease the implementation of the SPSYSE-TK methodology into organizations or groups with different characteristics.

The phases of the ECSS systems engineering methodology that are within the scope of this work are the phases 0, A, B, and C. Phase C, which consists in a detailed definition of the system that is being developed, within the scope of this work, would reduce to just a few processes as seen in the application case. This number of phases and the characteristics of them are not unique of the ECSS standards. In fact, NASA and ISO standards also recommend a similar phasing for general space projects. On the other hand, the SPSYSE-TK methodology is divided in three phases. Those three phases were actually conceived to embrace the considerations in which this work relies on. Specifically, the ECSS methodology indicates 4 phases, 33 processes, and

11 milestones (including 4 reviews) while the SPSYSE-TK methodology indicates 3 phases, 27 processes, and 7 milestones (including 3 reviews).

The following paragraphs describe in more detail the similarities and differences of the ECSS and the SPSYSE-TK methodology. Both methodologies are compared by phase. Specifically, phase 1 of the SPSYSE-TK methodology is compared with the phase 0 of the ECSS methodology; phase 2 of the SPSYSE-TK methodology is compared with the phase A of the ECSS methodology; and finally, phase 3 of the SPSYSE-TK methodology is compared with the phases B and C of the ECSS methodology.

5.2.2 **Phase 1 (SPSYSE-TK) vs phase 0 (ECSS)**

Table 5.1 shows the objectives of the phase 1 of the SPSYSE-TK methodology and the phase 0 of the ECSS methodology. Both phases produce a preliminary definition of the problem to be addressed (i.e. the mission) and preliminary proposals of systems that would address such problem. In both methodologies, this initial phase serves to identify and understand a set of needs and programmatic aspects, propose solutions for the space system, and define preliminary requirements and plans.

Table 5.1 - Objectives of phase 1 (SPSYSE-TK) vs. phase 0 (ECSS).

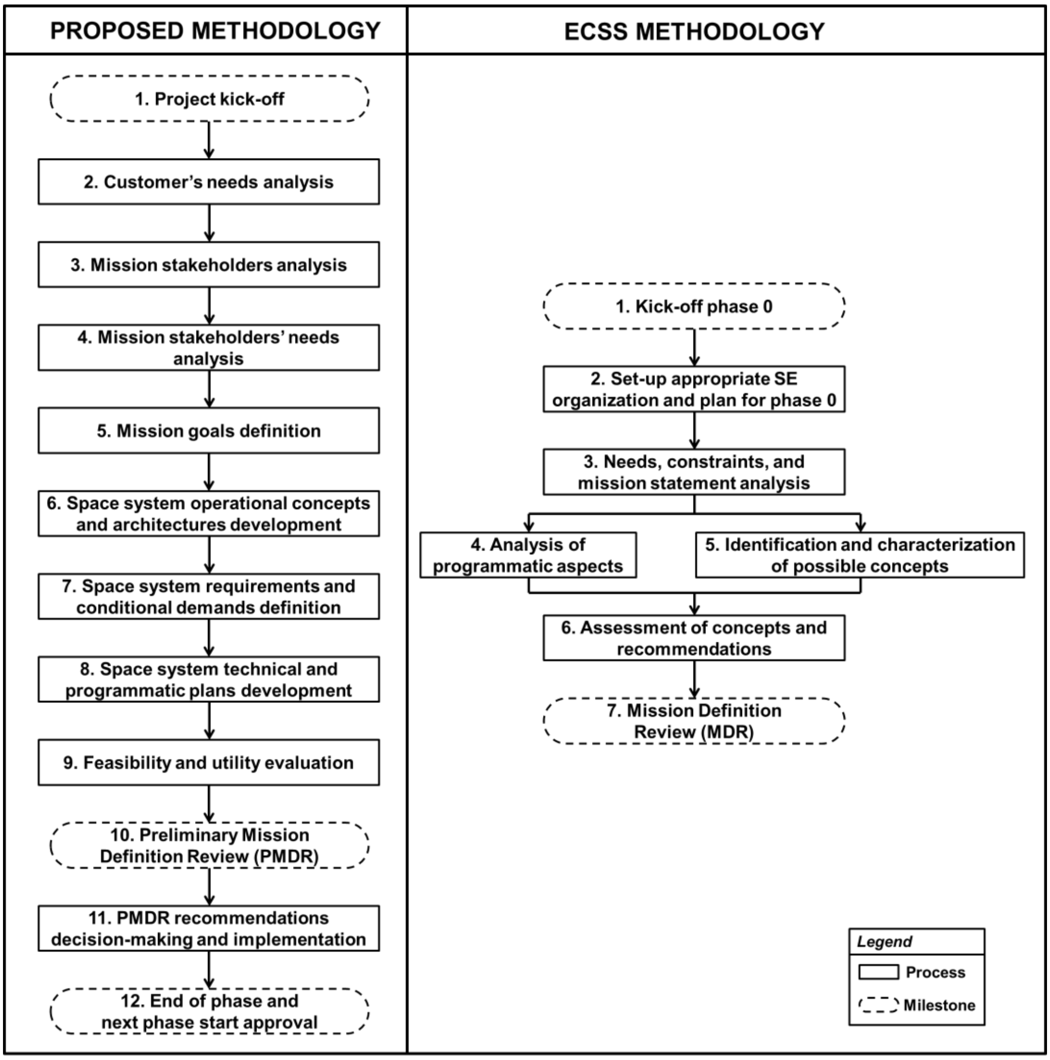
PROPOSED METHODOLOGY	ECSS METHODOLOGY
Main objective Define (in a preliminary way) the mission goals.	***Main objective*** Define a mission and propose possible associated system concepts.
Specific objectives • Support the identification and refinement of the needs of the customer and other relevant mission stakeholders; • Develop a set of preliminary mission goals (i.e. requirements and conditional demands); • Propose operational concepts and architectures for the space system (i.e. space system concept alternatives); • Develop preliminary requirements and conditional demands for each space system concept alternative as well as related technical and programmatic plans; • Perform a preliminary assessment of the feasibility and utility of the space system concept alternatives.	***Specific objectives*** • Support the identification and characterization of the mission needs, expected performance, goals, and operating constraints declared in the mission statement; • Develop technical requirements; • Perform a preliminary assessment of programmatic aspects supported by market and economic studies as appropriate; • Identify and propose possible mission concepts.

Source: Author production.

A fact that should be highlighted is that the SPSYSE-TK methodology uses the terms requirements and conditional demands to differ between matters that shall mandatorily be met (i.e. requirements) and matters that should preferably be met (i.e. conditional demands). A common practice among references is to use requirements for referring to both. However, in this work such separation is done not only to avoid misunderstandings but also to boost the understanding of what is really needed and what is desired. This discrimination is a key when considering that turnkey satellites will constitute the space segment since it is likely that alternative turnkey satellites will have different characteristics. Then, such discrimination aids the understanding of which of the characteristics would be necessary, which would add value, and which are irrelevant. It should be noticed that the terms requirements and conditional demands can be used for the mission or at different levels of the space system hierarchy. When used associated with the mission, both terms are referred in conjunction as mission goals.

Figure 5.1 shows the flowcharts of the phase 1 of the SPSYSE-TK methodology and the phase 0 of the ECSS methodology.

Figure 5.1 - Flowcharts of phase 1 (SPSYSE-TK) vs. phase 0 (ECSS).



Source: Author production.

Both methodologies begin this initial phase with a milestone. This milestone in both cases is a kick-off for ensuring that all the conditions are met to begin the project.

'2. Set-up appropriate SE organization and plan for phase 0' of the ECSS methodology consists in developing an initial systems engineering plan which defines the systems engineering tasks that are going to be performed according to the specific project characteristics. The initial systems engineering plan can be done by tailoring existing plans. This would mean that the systems engineering group can take the ECSS standard, analyze the processes that are proposed to be performed, and finally, select the ones that consider appropriate to such project. This was actually done within the application case. On the other hand, the SPSYSE-TK methodology represents as itself an initial systems engineering plan already tailored by the specificities of space projects involving the procurement of turnkey satellites. For the application of the SPSYSE-TK methodology only the allocation of resources (e.g. time, money, and personnel) would be needed before implementing it.

'3. Needs, constraints, and mission statement analysis' of the ECSS methodology consists in analyzing the needs and the mission statement of the customer to produce a first set of technical requirements. The SPSYSE-TK methodology in '2. Customer's needs analysis' not only includes the analysis of customer's needs but it also includes tasks for ensuring that such needs will be refined in order to be unambiguous and consistent. Ensuring the unambiguity and consistency of needs is important since such needs when declared by the customer or other stakeholder might not be clear. As Halligan (2012) states, although the customer understands better than anybody else the need that it is trying to satisfy, the customer cannot always express such need in clear or complete terms. Halligan (2012) adds that what the customer says it wants may not solve the problem or may not solve it optimally. Moreover, the SPSYSE-TK methodology complements the customer's needs by identifying other stakeholders that would be relevant for the mission ('3. Mission stakeholders analysis'). By doing this, new needs are identified and gathered during '4. Mission stakeholders' needs analysis'. Such needs are similarly refined and reviewed to produce at the end a set of unambiguous and consistent needs representing the interests of the relevant mission stakeholders. Only after these processes, the systems engineering group would have a solid knowledge and understanding of the problem and can establish together with the relevant mission stakeholders a set of requirements and conditional demands for the mission ('5. Mission goals definition'). In this case, the approach of the SPSYSE-TK methodology employs four processes to do what the ECSS methodology does in one. However, this approach represents a more detailed systematization of what should occur at the beginning of a project to identify a detailed and refined set of stakeholder needs.

It should be also highlighted that although the ECSS methodology recommends reviewing existing documents to identify and comprehend needs, the SPSYSE-TK methodology makes explicit the search of needs that might have not been declared by stakeholders (i.e. implicit needs).

The aforementioned matters are not only related to the specific types of space projects within the scope of this work. Instead, they represent a set of improvements related to the systems engineering effort that the SPSYSE-TK methodology possesses in comparison with the ECSS methodology. Those improvements represent a set of activities that other systems engineering references have established as important for the systems engineering effort implementation.

The SPSYSE-TK methodology, in '4. Mission stakeholders' needs analysis', after establishing the refined set of mission stakeholders' needs, recommends classifying the needs into essential, conditional, and optional. This classification is likely to result after a careful consideration of the needs together with the relevant mission stakeholders. Consequently, such set of essential, conditional, and optional needs would strongly represent what is required to address, what would be worthy to address (if possible), and what is irrelevant or unfeasible to address within the current mission, respectively. Furthermore, the SPSYSE-TK methodology indicates to rank conditional needs. That ranking would allow the relevant stakeholders to deliberate about what would be more important among the desired matters. Deliberating about that matter aims to help during the definition of the system. For instance, if those desired matters drive the space system operational concept or the architecture, then, knowing such ranking would be important when developing the space system concept alternatives. Such ranking might be also useful also when deciding among alternatives.

As it was indicated previously, the ECSS methodology in '3. Needs, constraints, and mission statement analysis' (specifically in task b.) suggests the definition of technical requirements from the identified needs. Technical requirements as defined by the ECSS explicitly exclude programmatic aspects such as cost and schedule. Then, programmatic aspects are analyzed in a subsequent process. Oppositely, the SPSYSE-TK methodology may gather information about programmatic aspects during the needs analysis and such aspects might be established as either requirements or conditional demands.

The set of technical requirements that are defined in '3. Needs, constraints, and mission statement analysis' of the ECSS methodology are classified by their type (e.g. functional, interface, environmental, operational). On the other hand, the SPSYSE-TK methodology, which employs the term requirements from '5. Mission goals definition' onwards, categorizes the requirements depending on if they are related to the mission or to a space system hierarchical level (e.g. mission requirements, space system requirements, segment requirements, and segment system requirements). When referring to space system requirements or segment requirements, they include the requirements of the lower levels. It should be noticed that the SPSYSE-TK methodology is compatible with using the types of requirements as described by the ECSS within the mission requirements or the requirements of the different space system hierarchical levels. The aforementioned logic applies similarly for the conditional demands.

The SPSYSE-TK methodology in '5. Mission goals definition' introduces the term mission goals, which encompasses the mission requirements (i.e. what shall be accomplished by the mission) and the mission conditional demands (i.e. what is desirable to be accomplished by the mission). The use of requirements and conditional demands is a singularity of the SPSYSE-TK methodology that enables the mission and the space system to be flexible enough to accommodate different alternatives of turnkey satellites available on the market while ensuring that the most important needs of the particular mission will be addressed.

While the ECSS methodology separates the problem domain from the solution domain in '3. Needs, constraints, and mission statement analysis', the SPSYSE-TK methodology separates the problem domain and the solution domain in '5. Mission goals definition' (problem domain) and '6. Space system operational concepts and architectures development' (solution domain). Furthermore, the SPSYSE-TK methodology splits the problem domain in all the needs that are identified and the needs that are actually relevant for the particular mission. This discrimination could enable to develop future space missions around the needs that were not met, or even to develop non-spatial systems for fulfilling those needs.

The ECSS methodology in '5. Identification and characterization of possible concepts' suggests developing concepts to fulfill the system technical requirements. On the other hand, in the next phase (i.e. phase A), the ECSS methodology indicates to begin the development of the space system architecture. This logic (i.e. defining requirements, then developing operational concept, and then developing architecture) is typical in traditional systems engineering approaches. The SPSYSE-TK methodology differs in such logic since in the first phase, specifically in '6. Space system operational concepts and architectures development', the SPSYSE-TK methodology results in the development of both the operational concept of the space system and its architecture. In fact, in the SPSYSE-TK methodology both terms are used always together and represented as a pair by the term 'space system concept'. This is done in this manner since it is assumed that the definition of an operational concept implies at least the definition of a generic or reference architecture. For the space systems that are within the scope of this work, it would be hard to produce an operational concept without implying an architecture.

An important fact that should be highlighted is that the SPSYSE-TK methodology in the development of the space system operational concept and architecture encourages the definition of the timelines when developing the operational scenarios. The ECSS methodology only mentions timelines from phase B onwards. The establishment of timelines during the first phase would help in the identification of requirements or conditional demands for the space system early during the development.

In the ECSS methodology, a set of technical requirements represents the basis for the development of the system. Concepts, architectures, and other subsequent outcomes are based on such technical requirements. Differently, in the SPSYSE-TK methodology, although a set of mission goals (i.e. requirements and conditional demands) represents the basis for the space system development, the alternative space system concepts derive into different sets of requirements and conditional demands. This is done in this way to consider the fact that each concept could vary according to the specific set of goals that is intended to meet and to avoid closing the solution space around a specific set of requirements too early before analyzing the market conditions. The drawback of this logic is that, if the concepts are too different, simultaneous developments should be performed around each of those sets and this could be hard to manage or could result in a work overload.

According to the ECSS methodology, in a broad sense, the systems engineering group should plan first the systems engineering effort; second, it should identify the needs; and then, it should identify concurrently programmatic aspects and possible system concepts. In the SPSYSE-TK methodology, this logic differs. First, the systems engineering group should identify the needs; second, it should identify potential concepts; and only then, it should plan its effort and estimate programmatic aspects. The logic in the SPSYSE-TK methodology enables to know what should be developed before planning the effort to develop it. This approach of the SPSYSE-TK methodology could enable to estimate programmatic aspects and detail plans with particular features related to a specific solution.

The ECSS methodology suggests the identification of programmatic aspects ('4. Analysis of programmatic aspects') concurrently with the identification of the system concepts ('5. Identification and characterization of possible concepts'). Differently, the SPSYSE-TK methodology suggests reviewing the programmatic aspects only after having the preliminary technical and programmatic plans. The logic of the ECSS methodology could allow detecting programmatic unfeasible concepts earlier than using the SPSYSE-TK methodology. However, the logic of the SPSYSE-TK methodology when estimating the programmatic aspects could allow having a better understanding about the space system concepts and the effort that would imply their development.

'6. Assessment of concepts and recommendations' of the ECSS methodology and '9. Feasibility and utility evaluation' of the SPSYSE-TK methodology are similar processes. However, the SPSYSE-TK methodology makes explicit the assessment of the technical feasibility, the programmatic feasibility, and the utility of the alternative concepts to the mission. Such detail is expected to aid in the identification of unfeasible concepts and in the identification of some concepts that are worth taking to the next phase. This selection of a reduced number of concepts advancing to the next phase should help when too many concepts were defined or when there is no much time, money, or other resource to manage the parallel study of several concepts.

The ECSS methodology illustrates reviews as unique milestones (e.g. '7. Mission Definition Review'). However, in practice, reviews involve preliminary and subsequent actions. Some of the recommendations that are issued during reviews are actually assessed and implemented later. The SPSYSE-TK methodology aimed to illustrate such logic. Consequently, the SPSYSE-TK methodology splits each review into a milestone ('10. Preliminary Mission Definition Review') and a subsequent process that results from that milestone ('11. PMDR recommendations decision-making and implementation'). That process represents the post-review assessment and implementation of the recommendations issued during the review.

It should be noticed at this point that the ECSS methodology refers to the review of the first phase as 'Mission Definition Review (MDR)'. However, the mission is actually refined in a subsequent phase. The SPSYSE-TK methodology refers to such review as 'Preliminary Mission Definition Review (PMDR)' to avoid misunderstandings and to enhance the fact that the mission goals could change after analyzing the market.

It should be also highlighted that is common to close phases after reviews and the aforementioned actions that result from reviews are actually implemented during the next phase. However, the author of the SPSYSE-TK methodology considers that the actions affect the outcomes of the current phase, and thus, they should be part of it. Then, the phase would be only closed after updates were performed. This is represented by '12. End of phase and next phase start approval'. This milestone is used also to release the outcomes of this phase and to obtain authorization to begin the next phase.

In a broad sense, it could be summarized that the first phase of both methodologies presents similarities in terms of what is done and what is obtained at the end of them.

5.2.3 Phase 2 (SPSYSE-TK) vs phase A (ECSS)

Table 5.2 shows the objectives of the phase 2 of the SPSYSE-TK methodology and the phase A of the ECSS methodology. Both phases produce a final definition of the problem to be addressed (i.e. the mission) and a preliminary proposal for the space system that would address the mission. On the one hand, in the ECSS methodology, this phase serves to refine the requirements and programmatic aspects, identify functional architectures and associated technology, and establish a system baseline. On the other hand, in the SPSYSE-TK methodology, this phase serves to identify what is available on the market, refine the preliminary definition of the space system alternatives according to such characteristics, assess the concept alternatives in detail, and baseline the space system concept and the mission goals.

Table 5.2 - Objectives of phase 2 (SPSYSE-TK) vs. phase A (ECSS).

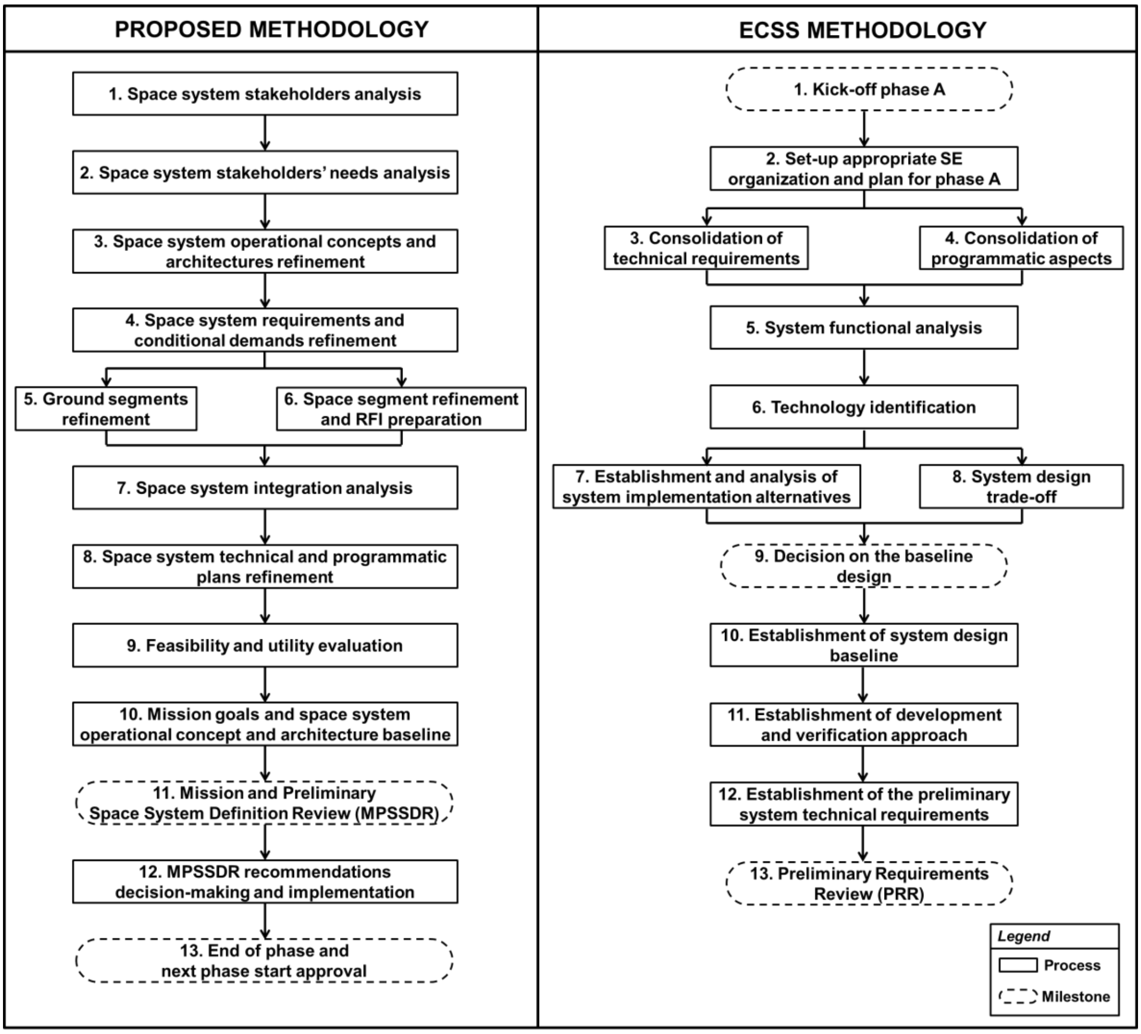
PROPOSED METHODOLOGY	ECSS METHODOLOGY
Main objective Define (in a final way) the mission goals and (in a preliminary way) the space system that will attend such goals.	***Main objective*** Finalize the expression of the needs identified in phase 0 and propose solutions to meet the perceived needs.
Specific objectives • Obtain preliminary information about the turnkey space segment solutions available in the market; • Refine the space system concept alternatives (including requirements, conditional demands, and plans) according to market characteristics; • Perform a detailed assessment of the feasibility and utility and the space system concept alternatives according to market characteristics; • Baseline the space system concept (i.e. space system operational concept and architecture); • Baseline the mission goals (i.e. requirements and conditional demands).	***Specific objectives*** • Elaborate possible system and operations concepts and system architectures; • Compare the possible system and operations concepts against the identified needs, to determine levels of uncertainty and risks; • Establish the functional decomposition; • Assess the technical and programmatic feasibility of the possible concepts by identifying constraints relating to implementation, costs, schedules, organization, operations, maintenance, production, and disposal; • Identify critical technologies and propose pre-development activities; • Quantify and characterize critical elements for technical and economic feasibility; • Propose technical solutions for the possible system and operations concept(s); • Establish the preliminary systems engineering plan for the project.

Source: Author production.

It should be also noticed that in this phase a system design baseline is established by the ECSS methodology. However, this is not highlighted in the specific objectives of this phase.

Figure 5.2 shows the flowcharts of the phase 2 of the SPSYSE-TK methodology and the phase A of the ECSS methodology.

Figure 5.2 - Flowcharts of phase 2 (SPSYSE-TK) vs. phase A (ECSS).



Source: Author production.

The ECSS methodology begins this phase with a milestone, which specifically is a kick-off for ensuring that all the conditions are met to begin the phase. In the SPSYSE-TK methodology, such verification and the authorization to begin the current phase was performed at the end of the phase 1 (specifically, in '12. End of phase and next phase start approval').

The discussion about '2. Set-up appropriate SE organization and plan for phase A' of the ECSS methodology during this phase would be similar to the discussion of its equivalent process in phase 0 ('2. Set-up appropriate SE organization and plan for phase 0').

The ECSS methodology includes a refinement of the technical requirements and programmatic aspects in the beginning of this phase (‘3. Consolidation of technical requirements’ and ‘4. Consolidation of programmatic aspects’). The SPSYSE-TK methodology includes the refinement of the space system requirements and conditional demands at a later process (‘4. Space system requirements and conditional demands refinement’). Before the refinement, the SPSYSE-TK methodology adds three processes: ‘1. Space system stakeholders analysis’, ‘2. Space system stakeholders’ needs analysis’, and ‘3. Space system operational concepts and architectures refinement’. The first two processes are introduced in the SPSYSE-TK methodology to capture potential needs that are important for the development of the space system but were not such important for the preliminary definition of the mission. Such new needs are used in the third process to refine the space system concept alternatives (i.e. space system operational concepts and architectures). Only after the refinement of the space system concept alternatives, the space system requirements and conditional demands are updated. It should be highlighted that in the previous phase the focus of similar processes was on identifying the mission goals; in this phase, the focus is on identifying what the space system should have to achieve mission goals instead.

Two processes that the ECSS methodology has differently from the SPSYSE-TK methodology are ‘5. System functional analysis’ and ‘6. Technology identification’. These processes, as shown in the application case, are somewhat incompatible for the use of turnkey satellites within the space system. Consequently, they are more appropriate for the development of new individual systems. They might be applicable for ground segments within the development effort. However, in such cases, it is likely that the implementation of such processes is outside of the systems engineering group responsibility. Functional analysis as described by the ECSS is used for defining one or more functional architectures. Within the scope of this work and as discussed previously, a generic architecture of the space system and its elements can be conceived from the first phase. Then, this process may be reduced to allocating or identifying new functions for the elements of the already defined space systems architecture up to the segment systems-level. Similarly, the technology identification process relates physical elements to the functional elements. This process makes more sense for the development of new systems where alternative solutions are available for implementing a specific function at subsystem- or equipment-levels. The assumptions and reinterpretation that was performed with these processes enabled the implementation of other subsequent processes.

According to the ECSS methodology, in a broad sense, the systems engineering group up to this point should refine the technical requirements, establish functional architectures, and then, identify technologies to implement the functional elements. This logic is typical for top-down approaches, and especially, when they involve subsystems or equipment development. Within the scope of this work, the implementation of this approach could result in identifying functions and related technologies for the satellites of the space segment that might not be feasible to achieve using turnkey satellites. Defining functions and technologies that are needed before the market analysis could close the solution space too much. Then, turnkey satellites might require too many modifications. In this case, a customized satellite might be needed instead. Similarly, some functions and technologies might be irrelevant to define since the satellite will be procured. In this case, it will be important for the satellite to fulfill the requirements independently of some of its internal functions or the technologies used.

After the space system requirements and conditional demands are updated, the SPSYSE-TK methodology adds to this phase two parallel processes. The first process (‘5. Ground segments refinement’) is proposed to identify the characteristics of the ground segments that would be a driver for the space segment satellites. The other process (‘6. Space segment refinement and RFI preparation) is proposed to refine the space segment requirements and conditional demands and prepare a Request For Information (RFI). The simultaneity of both process enables the definition of a set of requirements and conditional demands for the space segment that is consistent with the ground segments.

The RFI that should be prepared in ‘6. Space segment refinement and RFI preparation’ reflects what in practice is commonly performed for the procurement of satellites. This helps to identify not only the characteristics of the products that are on the market but also conditions or considerations regarding its use. In the ECSS methodology, the contact with the manufacturers seems only to happen in the phase B. Furthermore, ECSS standards refers to the contact mechanisms with manufacturers as Invitation To Tender (ITT), Request For Proposal (RFP), and Request For Quotation (RFQ). In the ECSS standards that were analyzed, there was not found any suggestion about performing an initial exploration of what is available on the market as suggested in the SPSYSE-TK methodology.

The SPSYSE-TK methodology also adds a process for refining the space system requirements and conditional demands according to the information gathered from the RFI responses while ensuring the compatibility among the segments (‘7. Space system integration analysis’). This process helps to identify the constraints that are imposed from the market on the space system, and consequently, it aims to reveal what should be modified to accommodate turnkey satellites in the solution.

The ECSS methodology in ‘7. Establishment and analysis of system implementation alternatives’ establishes feasible overall system implementation alternatives and detail them to achieve overall system optimization. As described in the application case, this process is appropriate for the development of new individual systems since it establishes implementation alternatives for the previously defined functional architectures, which are likely to be developed at subsystem- or lower levels. As shown in the application case, such process is somewhat incompatible and requires a reinterpretation to be applicable within the scope of this work. Thanks to the adaptation and reinterpretation of the previous processes as well as the reinterpretation of this process, the system alternatives considered details up to the segment systems-level enabling the implementation of the process for the described mission.

It should be highlighted that the tasks of '8. System design trade-off' in the ECSS methodology are likely to be related to the comparison and ranking of the different implementation alternatives at subsystem- or lower levels. However, due to the reinterpretation of the process as described in the application case, this process was applicable within the scope of this work. Then, it can be stated that the processes '9. Feasibility and utility evaluation' of the SPSYSE-TK methodology and '8. System design trade-off' of the ECSS methodology would be similar. Both processes consider both technical and programmatic aspects for comparing alternatives. However, in the SPSYSE-TK methodology the technical and programmatic plans are refined before the evaluation, specifically in '8. Space system technical and programmatic plans refinement'.

It should be highlighted that the milestone '9 Decision on the baseline design' in the ECSS methodology is likely to be related to the selection of a baseline design based on the different implementation alternatives at subsystem- or lower levels. However, due to the reinterpretation of the previous processes, this milestone was applicable within the scope of this work. Then, it can be stated that the process '10. Mission goals and space system operational concept and architecture baseline' of the SPSYSE-TK methodology and the milestone '9 Decision on the baseline design' of the ECSS methodology would be similar. It should be noticed that in the SPSYSE-TK methodology it was considered as a process instead of a milestone to enhance that some tasks should be performed. First, there is a decision on the space system operational concept and architecture according to mission utility results. However, after that baseline, the SPSYSE-TK methodology recommends to review the mission goals according to the chosen operational concept and architecture. This opens an opportunity to update the mission goals according to the market characteristics, which is a relevant matter in the projects within the scope of this work and a matter that is not covered by traditional systems engineering methodologies such as ECSS's.

It should be noticed for '11. Establishment of the development and verification approach' of the ECSS methodology that this process refers to the establishment of development of verification approaches that are likely to be performed by the satellite manufacturer or the groups responsible for the ground segment systems development. Consequently, it is somewhat incompatible within the scope of this work. However, due to the reinterpretation of the processes as described in the application case, this process was applicable within the scope of this work. Within this reinterpretation, the process '11. Establishment of the development and verification approach' of the ECSS methodology is covered by '8. Space system technical and programmatic plans development' of the SPSYSE-TK methodology. Furthermore, the SPSYSE-TK methodology does not restrict to development and verification plans. It also can cover other plans such as mission operations plan, procurement plan, and decision management plan.

On the one hand, in the ECSS methodology, '10 Establishment of system design baseline' and '12. Establishment of the preliminary system technical requirements' aim to establish a set of preliminary requirements for the system to be developed. This results in the end of phase A. These processes, as shown in the application case, are likely to be related to subsystem- or lower levels. However, due to the reinterpretation of some previous processes as described in the application case, the aforementioned processes could be applied within the scope of this work at higher levels in the space system hierarchy to establish the preliminary requirements for the space system up to the segment systems-level. On the other hand, the focus of the SPSYSE-TK methodology at the end of phase 2 (specifically in '10. Mission goals and space system operational concept and architecture baseline') is to finalize the mission goals and the space system concept (i.e. operational concept and architecture) ensuring that they are compatible with the market-imposed characteristics.

As it was described for the phase 1, the SPSYSE-TK methodology illustrates the review logic as a milestone (‘11. Mission and Preliminary Space System Definition Review’) and a subsequent process that results from that milestone (‘11. MPSSDR recommendations decision-making and implementation’).

It should be noticed at this point that the ECSS methodology refers to the review of the second phase as ‘Preliminary Requirements Review (PRR)’. The SPSYSE-TK methodology refers to such review as ‘Mission and Preliminary Space System Definition Review (MPSSDR)’ to enhance that the mission is completely defined within this phase and that the space system has been refined up to a more mature (but still preliminary) definition.

Similarly to phase 1, the SPSYSE-TK methodology adds at the end of this phase a milestone (‘13. End of phase and next phase start approval’) to release the outcomes of this phase and to obtain authorization to begin the next phase.

In a broad sense, it could be summarized that the second phase of the SPSYSE-TK methodology allows differentiating it from ECSS methodology. Although some processes present similarities, the SPSYSE-TK methodology introduces within this phase the market analysis through RFIs, the refinement (or integration) of requirements according to the market analysis, and the update of the mission goals to be compatible with market-imposed characteristics.

5.2.4 Phase 3 (SPSYSE-TK) vs phases B+C (ECSS)

Table 5.3 shows the objectives of the phase 3 of the SPSYSE-TK methodology and the phases B and C of the ECSS methodology. In the SPSYSE-TK methodology, phase 3 results in the final definition of the space system. On the other hand, in the ECSS methodology, phase B results into a preliminary definition of the space system and phase C results into its final definition. In the

ECSS methodology, phases B and C serve to refine requirements and programmatic aspects, identify physical architectures, begin the bid process, select suppliers, baseline the physical architecture, and finalize the plans for the subsequent phases. On the other hand, in the SPSYSE-TK methodology, phase 3 serves to obtain detailed proposals for the space segment; refine the requirements and conditional demands of the ground segments according to such proposals; establish space system implementation alternatives based on the space segment proposals; assess the system implementation alternatives in detail; select an implementation alternative; and finally, prepare the procurement and development of the segments systems.

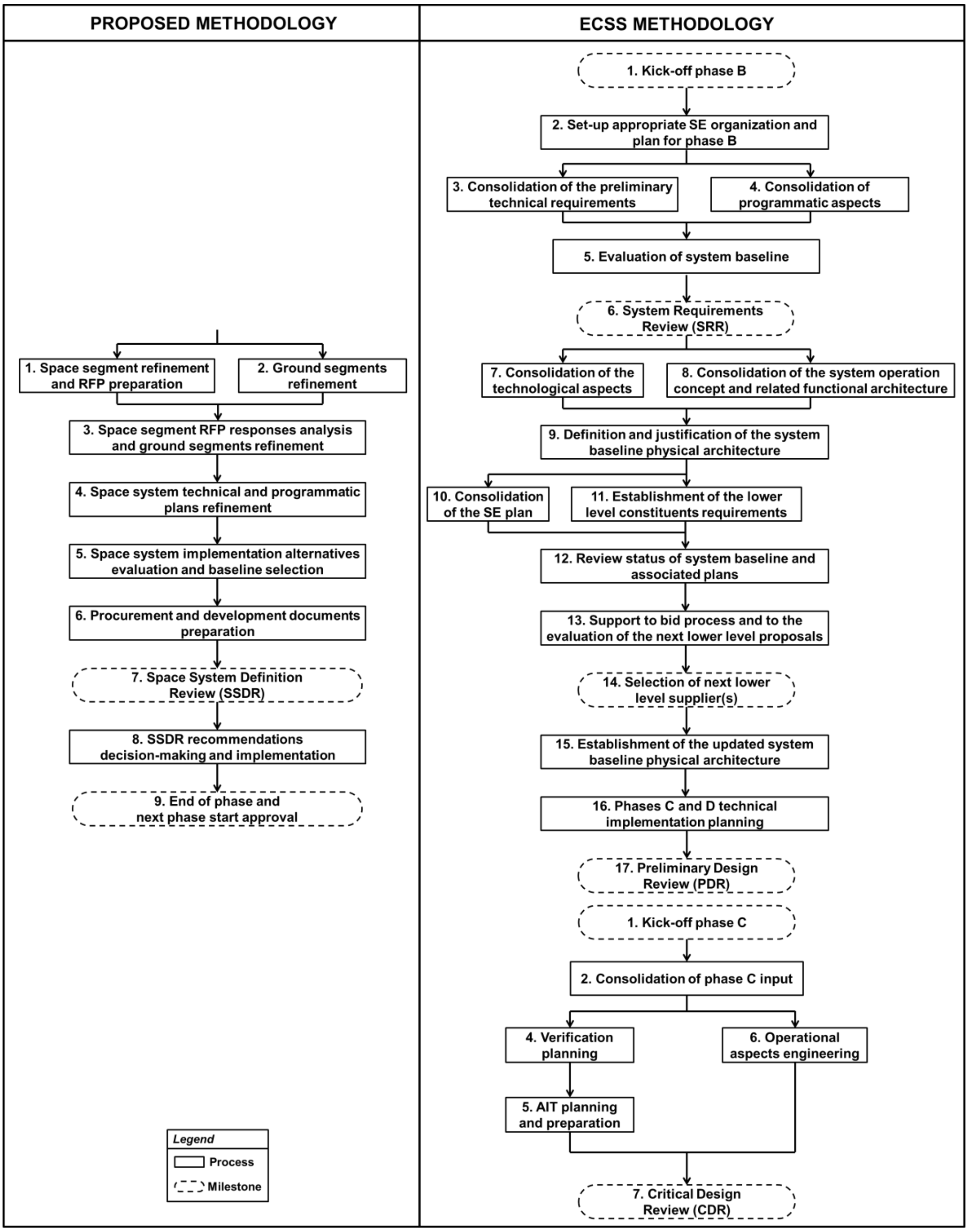
Table 5.3 - Objectives of phase 3 (SPSYSE-TK) vs. phases B+C (ECSS).

PROPOSED METHODOLOGY	ECSS METHODOLOGY
Main objective Define (in a final way) the space system will perform the mission	***Main objective*** Establish the system definition (preliminary in phase B and detailed in phase C) for the solution selected at end of Phase A and demonstrate that the system meets the technical requirements according to the schedule, the budget, the target cost, and the organization requirements
Specific objectives • Obtain detailed proposals for the space segment; • Obtain detailed proposals for the ground segments; • Establish some space system implementation alternatives (i.e. space segment proposal plus ground segment proposals); • Perform a detailed assessment of the mission utility of the several space system implementation alternatives; • Selection of a space system implementation alternative; • Support the preparation of procurement documents that will be needed to buy the selected turnkey space segment solution as well as other documents that will be needed to make or buy the ground segments (including final technical and programmatic plans).	***Specific objectives*** • Confirm technical solution(s) for the system and operations concept(s) and their feasibility with respect to programmatic constraints; • Conduct "trade-off" studies and select the preferred system concept, together with the preferred technical solution(s) for this concept; • Finalize the systems engineering plan and other engineering plans. • Finalize the detailed design definition of the system at all levels for the selected system concept and retained technical solution(s); • Completion of assembly, integration, and test planning for the system and its constituent parts; • Detailed definition of internal and external interfaces.

Source: Author production.

Figure 5.3 shows the flowcharts of the phase 3 of the SPSYSE-TK methodology and the phases B and C of the ECSS methodology.

Figure 5.3 - Flowcharts of phase 3 (SPSYSE-TK) vs. phases B+C (ECSS).



Source: Author production.

The ECSS methodology, as in phases 0 and A, begins this phase with a milestone, which specifically is a kick-off for ensuring that all the conditions are met to begin the phase. In the SPSYSE-TK methodology, such verification and the authorization to begin the current phase was performed at the end of the phase 2 (specifically, in ‘13. End of phase and next phase start approval’).

The discussion about ‘2. Set-up appropriate SE organization and plan for phase B’ of the ECSS methodology during this phase would be similar to the discussion of its equivalent process in phase 0 (‘2. Set-up appropriate SE organization and plan for phase 0’).

It should be noticed that as described for similar processes of the phase A of the ECSS methodology, the processes ‘5. Evaluation of system baseline’, ‘7. Consolidation of the technological aspects’, ‘12. Review status of system baseline and associated plans’, and ‘16. Phases C and D technical implementation planning’ are somewhat incompatible with the use of turnkey satellites. They refer to some lower level requirements and plans that are likely to be defined by the satellite manufacturers. Those processes could be applicable for the ground segments systems within the development effort but even in those cases, such processes might be responsibility of other engineering disciplines groups rather than the systems engineering group. Some of this process were reinterpreted to be applicable within the scope of this work.

After reinterpretation, the processes ‘3. Consolidation of the preliminary technical requirements’, ‘4. Consolidation of programmatic aspects’, ‘5. Evaluation of system baseline’, ‘11. Consolidation of the SE plan’, ‘12. Review status of system baseline and associated plans’, and ‘16. Phases C and D technical implementation planning’ of the ECSS methodology represent refinements of technical requirements, plans, and programmatic and technical aspects of the space system and its elements. Such refinements are covered in the SPSYSE-TK methodology along the first four processes of phase 3. Similarly, the refinement of the operational concept and architecture that happens in ‘8. Consolidation of the system operation concept and related functional architecture’ of the ECSS methodology was actually performed during the previous phase of the SPSYSE-TK methodology (specifically, before the baseline of the space system operational concept and architecture that happens in ‘10. Mission goals and space system operational concept and architecture baseline’).

The review ‘6. System Requirements Review (SRR)’ of the ECSS methodology has not its equivalent review in the SPSYSE-TK methodology. In the SPSYSE-TK methodology, the requirements, the preliminary definition of the system, and the preliminary verification approach, which are reviewed at this milestone in the ECSS methodology, are supposed to be already reviewed in the previous phase at ‘11. Mission and Preliminary Space System Definition Review (MPSSDR)’.

An important issue that should be highlighted is that the ECSS methodology begins the characterization of the operational scenarios (including its timelines) in ‘8. Consolidation of the system operational concept and related functional architecture’. As it was described before, the SPSYSE-TK methodology characterizes the operational scenarios (including its timelines) from the first phase. That characterization of the operational scenarios from the first phase would help in the identification of requirements or conditional demands for the space system early during the development.

The ECSS methodology in ‘9. Definition and justification of the system baseline physical architecture’ and ’11. Establishment of the lower level constituents requirements’ details the architecture of the elements of the space system, adding details for all its functions and interfaces. This logic, which is typical for top-down approaches, is incompatible with the use of turnkey satellites. Those processes could be applicable for the ground segments systems within the development effort but even in those cases, such processes might be responsibility of other groups rather than the systems engineering group. The application of these processes to define lower level requirements of a satellite that will be procured could result in the definition of functions and interfaces that might not be feasible to achieve using turnkey satellites. Especially, due to the fact that the market analysis has not been performed yet, this could close the solution space too much, requiring too many modifications on the turnkey satellites to be used in the space system. Then, a customized satellite might be more appropriate.

On the one hand, the ECSS methodology in ‘13. Support to bid process and to the evaluation of the next lower level proposals’ for the first time recommends the preparation of a bid process. This process as shown in the application case would be related to subsystem- or lower levels. However, due to the reinterpretation that was performed in the application case, such process could be applied within the scope of this work to ask for proposals at a segment-level. Then, the bid process within the scope of this work would mean asking for proposals of the space segment, which will reflect the turnkey satellites available on the market. The ECSS methodology does not state which type of request should be emitted to ask for the proposals. However, since the requirements of the space system and its elements are detailed at this point, the request is likely to be an RFP. However, this is not specifically stated by the ECSS methodology. On the other hand, the SPSYSE-TK methodology specifically suggests issuing an RFP in ‘1. Space segment refinement and RFP preparation’. It should be highlighted that at this point, due to the continuous refinement of the space system requirements that the ECSS methodology recommends, the RFP issued following the ECSS methodology might be more specific than the RFP issued following the SPSYSE-TK methodology. As mentioned before, this could close the solution space too much, requiring too many modifications on the turnkey satellites. Again, in this case a customized satellite might be more appropriate.

The SPSYSE-TK methodology indicates the parallel execution of ‘1. Space segment refinement and RFP preparation’ and ‘2. Ground segments requirements’. By doing this, the SPSYSE-TK methodology aims to produce a RFP harmonized and consistent with the expected characteristics of the ground segments, and thus, avoiding too much effort on the integration of the segments.

The SPSYSE-TK methodology in ‘3. Space segment RFP responses analysis and ground segments refinement’ suggests refining and harmonizing the requirements of the ground segments according to the space segment proposals. In the ECSS methodology, ‘15. Establishment of the updated system baseline physical architecture’ would be similar in purpose after the reinterpretation that was performed on this process. It should also be noticed that in the SPSYSE-TK methodology, such harmonization is performed before the selection of a space system implementation alternative, and thus, before the selection of a space segment proposal. Contrariwise, in the ECSS methodology, such harmonization is performed after the selection of the space segment proposal. In the SPSYSE-TK methodology, the idea is that the selection of a space segment proposal occurs only after the entire effects of such proposal on the technical and programmatic aspects of the space system are known in detail.

The SPSYSE-TK methodology adds in ‘3. Space segment RFP responses analysis and ground segments refinement’ the establishment of proposals for the ground segment, which are thought as equivalent to the RFP responses of the space segment but for the ground segments instead. This task is introduced to highlight that the effort of the systems engineering group ends at the segment systems-level and that the detailed definition of the ground segments is responsibility of another group or organization.

According to author’s criteria, the process ‘13. Selection of next lower level supplier(s)’ of the ECSS methodology, as the name of this process refers, typically reduces to the selection of who is the supplier of the next lower level element. It would be in that way since proposals of the suppliers (or manufacturers) are supposed to meet all the requirements of the RFP, and thus, the proposals would be very similar. Then, the selection would reduce only to selecting the supplier according to programmatic factors, such as delivery time, price, maturity of the proposal, or manufacturer’s experience. Furthermore, as shown in the application case, this process is likely to be related to subsystem- or lower levels in a traditional development. However, due to the reinterpretation that was performed in the application case, such process could be applied within the scope of this work to assess proposals at a segment-level. Within this reinterpretation, the selection among turnkey satellite alternatives would get more complicated since it would depend not only on programmatic aspects but also on the technical characteristics of the alternatives. Consequently, in the SPSYSE-TK methodology, as it was said before, the selection among alternatives covers the entire space system characteristics (i.e. technical and programmatic aspects of the space and the ground segments). This is introduced by the process ‘5. Space system implementation alternatives evaluation and baseline selection’, which consists in an overall evaluation of the space system implementation alternatives and the selection of the alternative that provides the highest value to the mission.

The SPSYSE-TK methodology introduces also the process ‘6. Procurement and development documents preparation’ to finalize the plans and documents that are needed in the subsequent phases for the production (manufacturing, assembly, integration, and test), utilization, support, and disposal of the space system and its elements.

The review ‘17. Preliminary Design Review (PDR)’ of the ECSS methodology suggests verifying and assessing the preliminary definition of the system, the requirements, the product and work decompositions, and final plans. On traditional developments, these plans and products decomposition would be related to hierarchical levels such as subsystem-level or lower. However, the reinterpretation that was performed allows the consideration of this review at the highest hierarchical levels (up to segment systems-level). Within this reinterpretation, some of the inputs for this review might be responsibility of the selected satellite manufacturer or of the engineering discipline groups responsible for the development of the ground segment systems. In the SPSYSE-TK methodology, some preliminary aspects such as the preliminary definition of the space system are supposed to be already reviewed in the previous phase at '11. Mission and Preliminary Space System Definition Review (MPSSDR)' while detailed aspects such as final plans are supposed to be reviewed later in the current phase at '7. Space System Definition Review (SSDR)'.

The phase C of the ECSS methodology includes detailed design activities that only makes sense at low levels such as subsystem- and equipment-levels. Consequently, they will be performed by the satellite manufacturer or by the groups responsible for the ground segments systems. Similarly, phase C includes several monitoring, coordination, and management activities that are outside of the scope of this work.

Phase C also includes activities specific for the development of satellites such as the assembly, integration, and tests of the engineering and the structural and thermal models. All this activities are incompatible with a space project considering the procurement of turnkey satellites.

The following paragraphs describe the only applicable processes of the phase C that are within the scope of this work. Furthermore, the relation with processes in the SPSYSE-TK methodology is also described.

The processes '4. Verification planning' and '5. AIT planning and preparation' are covered by the SPSYSE-TK methodology in '4. Space system technical and programmatic plans refinement'. It should be noticed that the tasks of these two processes of the ECSS methodology are somewhat incompatible within the scope of this work. They are typically appropriate to be applied at low hierarchical levels and consequently, they might be responsibility of the satellite manufacturer or of the engineering disciplines groups responsible of the ground segments systems development. However, with the reinterpretation of these processes that was described in the application case, these two processes could be applied at higher hierarchical levels and thus could be applied within the scope of this work.

The process ‘6. Operational aspects engineering’ of the ECSS methodology is expected to be covered by the SPSYSE-TK methodology in ‘4. Space system technical and programmatic plans refinement’. However, in phases 1 and 2 of the SPSYSE-TK methodology part of the operational aspects are expected to be already defined. It should be noticed that the tasks of this process of the ECSS methodology are somewhat incompatible within the scope of this work. Such process refers to scenarios that would not be applicable in the context of a procurement of turnkey satellites (e.g. installation and launch scenarios). However, as described in the application case, this process might be reduced in extent to be applied within the scope of this work only for the mission operations.

The review ‘7. Critical Design Review (CDR)’ of the ECSS methodology suggests assessing the final definition of the system (including the interfaces) and the assembly, integration, and test plans. On traditional developments, these final definition goes up to a segment system-level, so for instance, it might be applied for a satellite development. However, this milestone might be reinterpreted in order to be applied at the space system–level and consequently, be applicable within the scope of this work. In the SPSYSE-TK methodology, some of these final aspects such as final plans and the final definition of the space system should be reviewed at ‘7. Space System Definition Review (SSDR)’.

It should be highlighted that the SPSYSE-TK methodology indicates performing a unique review instead of two reviews (one preliminary and one final) as indicated by the ECSS. This was conceived in this way since phase C of the ECSS reduces too much its scope when applied to the specificities of projects considering the procurement of turnkey satellites (as demonstrated in the application case). Consequently, it can be combined with phase B.

As it was described for the phases 1 and 2, the SPSYSE-TK methodology illustrates the review logic as a milestone ('7. Space System Definition Review') and a subsequent process that results from that milestone ('18. SSDR recommendations decision-making and implementation').

Similarly to phases 1 and 2, the SPSYSE-TK methodology adds at the end of this phase a milestone ('9. End of phase and next phase start approval') to release the outcomes of this phase and to obtain authorization to begin the next phase.

In a broad sense, it could be summarized that the third phase of the SPSYSE-TK methodology presents some similarities with the ECSS methodology in terms of what is done and what is obtained at the end of them. However, before preparing the RFP, the ECSS methodology aims to produce a more detailed definition of the space system than the SPSYSE-TK methodology, which could make hard to accommodate turnkey satellites. On the other hand, the SPSYSE-TK methodology bases its processes, the sequence among them, and their tasks in a way specifically conceived to allow the accommodation of turnkey satellites within the space system. This represents a significant difference between two methodologies.

6 CONCLUSIONS

This chapter presents a set of conclusions about the work and the SPSYSE-TK methodology. First section of this chapter demonstrates the fulfillment of the objectives of this work. Second section highlights about the contributions of this work. Third section argues about the expected impacts of this work. Fourth section highlights the limitations of the SPSYSE-TK methodology. Finally, fifth section suggests potential future works in the line of this work.

6.1 Fulfillment of objectives

The main objective of this work was to propose a methodology for space systems engineering based on the procurement of turnkey satellites. Chapter '3 SPSYSE-TK: the proposed methodology' describes such proposal. Furthermore, the proposed methodology was initially conceived to adapt traditional space systems engineering approach for accommodating the use of turnkey satellites. As described in chapter '5 SPSYSE-TK methodology assessment', the SPSYSE-TK methodology contains top-down activities of the traditional systems engineering approach for engineering space systems while considering the bottom-up characteristics and the constraints that would be imposed by the use of turnkey satellites. Consequently, the main objective of this work was achieved.

A specific objective of this work was to develop the proposed methodology based on traditional space systems engineering methodologies and particular considerations for taking into account concerns associated to the procurement of turnkey satellites. As described in chapter '1.3 Research approach', the SPSYSE-TK methodology was constructed from the analysis of numerous recommendations of ECSS's, NASA's, SMAD's, ASSE's, ISO/IEC/IEEE's, and INCOSE's systems engineering references, which were adapted to incorporate the procurement of turnkey satellites within the systems engineering effort. Consequently, this objective was achieved.

Another specific objective of this work was to apply the methodology to an application case to illustrate how the methodology could be used and to produce facts for judging its appropriateness. Chapter ‘4 Application case’ illustrates the application of the SPSYSE-TK methodology and a traditional systems engineering methodology (specifically, the ECSS methodology) in the context of a particular remote sensing mission. Consequently, this objective was achieved.

The last specific objective of this work was to assess the methodology and the application case for concluding about the appropriateness of the methodology for projects considering the procurement of turnkey satellites while showing the similarities and particularities in comparison with a traditional space systems engineering methodology. Chapter ‘5 SPSYSE-TK methodology assessment’ contains several arguments that demonstrate the appropriateness of the SPSYSE-TK methodology for space projects based on the procurement of space projects. Additionally, section ‘5.2 SPSYSE-TK methodology vs. ECSS traditional methodology’ presents the similarities and particularities of the SPSYSE-TK methodology with respect to the ECSS systems engineering methodology. The reasons for choosing the ECSS methodology as a reference are described in chapter ‘4 Application case’.

This work covers the engineering of space systems, including their concept, specification, and architecture. Consequently, it fits within the line of research in ‘Design, specification, architecture, and space systems management’ of the INPE’s graduate course in Space Systems Engineering and Management.

6.2 **Contributions**

This work proposes a methodology for space systems engineering, which has been tailored to accommodate the use of turnkey satellites. Specifically, this work provides a particular set of phases, process, and activities, which have been conceived to be used in space projects that will be based on the procurement of turnkey satellites. The methodology is explained in detail in chapter '3 SPSYSE-TK: the proposed methodology'. The SPSYSE-TK methodology combines traditional top-down activities of the systems engineering approach to define a space system capable of fulfilling the stakeholders' needs in the best way with bottom-up activities that enables the identification of constraints that turnkey satellites would impose on the space system. As section '2.3 Systems engineering with the use of commercial products' presents, there was not found any previous record of methodologies with such focus in existing researches.

This work brings to the space industry some findings that have been identified as valuable to other industries. As section '2.3 Systems engineering with the use of commercial products' presents, several researches –mostly in the software industry- have proven that development efforts must be adapted when commercial products are going to be considered within such efforts to avoid risks and pitfalls. As section '5.1 SPSYSE-TK methodology vs. previous findings' describes, the SPSYSE-TK methodology embraces most of the findings that those researches identified regarding the use of commercial products.

The traditional methodologies are oriented towards a customized satellites development which are typically related to a specific and strict set of requirements. On the other hand, the SPSYSE-TK methodology aims to increase the use of available resources by allowing flexibility on the requirements. Specifically, this work suggests the use of turnkey satellites. Turnkey satellites are increasing their availability and diversity on the satellites market. Additionally, turnkey satellites might provide some of the benefits that commercial products have provided to other industries, such as lower costs, shorter times to deployment, and reduced risks.

An indirect contribution of this work is that the SPSYSE-TK methodology reflects in a detailed and systematic view a practice that is commonly performed in the space industry, which is to define space missions with knowledge of what already exists on the market and to procure satellites for fulfilling such missions. As section ‘2.3 Systems engineering with the use of commercial products’ presents, it was not found any record of this practice in academic or scientific researches.

Another indirect contribution of this work is the update of the ECSS-E-10 Part1B standard based on the terms used within its subsequent version (ECSS-S-ST-10C). Additionally, based on that update, this work characterizes the ECSS methodology in terms of the essential content that is produced along its processes rather than on specific deliverable documents as described in ECSS-E-10 Part 1B. Furthermore, this work provides a tailoring and reinterpretation of the ECSS methodology in which such methodology might be applied to develop space projects based on the procurement of turnkey satellites, as ‘Attachment C - application of ECSS methodology’ describes. It should be noticed that the aforementioned update, characterization, and tailoring were performed according to author’s interpretation.

6.3 **Expected impacts**

This work aims to support the continuous increase of the number of space projects in Latin America while taking advantage of the wide availability of turnkey satellites. As described in chapter ‘1.1 Motivation’, the current increase of Latin American countries developing space projects based on the procurement of satellites as well as the current satellites market offering a wide range of options of turnkey satellites open an opportunity to the SPSYSE-TK methodology to be implemented. Furthermore, the proposed methodology was conceived to be general enough to be applicable by several systems engineering groups, regardless its country, documentation policies, or specific skills. Consequently, the SPSYSE-TK methodology aims to be a useful reference for different systems engineering groups.

The level of benefits that can be obtained from the application of the SPSYSE-TK methodology will depend on how the systems engineering group as well as other relevant groups or organizations participating in the space project can follow the methodology without limitations with respect to legal aspects, such as those related to the procurement process that exists typically in public organizations.

The application of the SPSYSE-TK methodology expects to arouse interest in space technology. Even when the focus of the SPSYSE-TK methodology is not on the development of space technology, the application of the proposed methodology could lead to local technology developments in a mid or long-term. Wood and Weigel (2012) show that several countries have invested first in owning and operating at least one satellite, and later those countries exhibited evidence of being working towards developing a local capability to manufacture such satellites. In this context, if applied by Brazilian or other Latin American organizations or groups, the application of the SPSYSE-TK methodology could arouse their interest in space technologies and could therefore result in the eventual development of space products within those organizations or groups. Furthermore, if such interest is triggered, this could lead INPE to pass consolidated satellite technologies or products (e.g. the Multi-Mission Platform in a medium-term future) to the Brazilian industry for the qualification of its personnel. Then, Brazilian organizations and groups could offer turnkey satellites to other countries organizations and groups, and thus, INPE could avoid repeating activities.

The SPSYSE-TK methodology proposed in this work could be also useful to INPE in an industrial architecture where INPE had a partner that can act as a prime contractor for a customer. The prime contractor can be the responsible for the development of the whole space system. INPE could perform or support the activities of the SPSYSE-TK methodology related to the mission definition due to its broad and extensive knowledge in space applications (e.g. remote sensing, meteorology, space weather) as well as missions operations and satellites control. The prime contractor could perform the activities of the SPSYSE-TK methodology related to the space system definition and procurement of turnkey satellites due to its freedom to contract third parties such as satellite manufacturers. Although the space system that will result of this effort would belong to the customer, the industrial architecture might involve some agreements that allow INPE to expand the products or services that INPE can use or offer for fulfilling particular needs of Brazil as well as some technology transfer agreements to increase the competences of INPE’s human resource.

Finally, the use of turnkey satellites as suggested in this work might provide some of the benefits that commercial products have provided to other industries (e.g. lower risks, costs, and schedules) as well as other benefits already used in the space industry such as technology transfer and the use of services before deployment of the space system.

6.4 Limitations

The SPSYSE-TK methodology was conceived to be applicable by organizations and groups with freedom to contract third parties. This is mainly the case of private organizations or groups. Public organizations or groups with the capability to request exemptions that enable the contract of third parties could also use the SPSYSE-TK methodology. However, the SPSYSE-TK methodology is probably not applicable (or at least not without modifications) in most of the public organizations or groups since they have restrictions regarding the procurement or execution of contracts.

The SPSYSE-TK methodology focuses on systems engineering, and thus, some additional objectives, processes, and activities should be added to consider management, product assurance, operations, and other groups efforts required for developing a space system. Similarly, the SPSYSE-TK methodology leaves out some activities such as verification, validation, control, configuration management, information management. Consequently, the SPSYSE-TK methodology will require modifications to consider such activities.

The SPSYSE-TK methodology was conceived for developing space systems whose space segment orbits the Earth (i.e. satellite systems). Consequently, the SPSYSE-TK methodology is probably not applicable (or at least not without modifications) for interplanetary missions.

The SPSYSE-TK methodology, as Figure 3.1 illustrates, is applicable to those space projects in which it was previously defined that the satellites constituting the space segment will be procured, and furthermore, that they will be turnkey satellites. The use of turnkey satellites that is proposed in this work could result in limiting the fulfillment of some needs or limiting the performance of the space system.

6.5 Potential future works

Potential future works in the line of this work may be the following:

- Implementation of the SPSYSE-TK methodology (or partial implementation) by potential users in order to validate the methodology and to identify potential improvements;
- Submission of the SPSYSE-TK methodology to a structured review (e.g. Delphi method) by external specialists in order to identify potential improvements;
- Extension of the SPSYSE-TK methodology to include other systems engineering processes such as verification, validation, control, configuration management, information management;
- Extension of the SPSYSE-TK methodology to cover all the lifecycle phases of a space project;
- Extension of the SPSYSE-TK methodology to cover other groups efforts (e.g. management, product assurance, operations, production).

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GLOSSARY

Activity – a set of cohesive tasks of a process. (ISO et al., 2015a)

Capability – functionality, service, task, or activity that a stakeholder needs. (LARSON et al., 2009)

Conditional demand – matters that should preferably be met.

Constraint – any limitation that have been imposed by a stakeholder.

Contract – a mutually binding agreement that obligates a seller to provide a specified product or service or result and obligates the buyer to pay for it. (PMI, 2008)

Control – in an IDEF0 model, a condition or set of conditions required to produce correct output. (ISO et al., 2012)

Customer – organization or person that receives a product or service. Some customer synonyms are client and acquirer. (ISO et al., 2015a)

Item – piece of hardware or software or combination of hardware and/or software, usually self-contained, which performs a distinctive function. (ISO, 2007)

Mechanism – in an IDEF0 model, the means used to transform inputs into outputs. (ISO et al., 2012)

Methodology – a system of activities embodied into a temporal and a logical dimension (i.e. phases and processes, respectively).

Need – a thing that is wanted or required by a stakeholder.

Non-functional features – characteristics that define quality attributes expected or imposed by stakeholders, including constraints. (LARSON et al., 2009)

Objective – something toward which work is to be directed, a strategic position to be attained, or a purpose to be achieved, a result to be obtained, a product to be produced, or a service to be performed. (PMI, 2008)

Opportunity – a condition or situation favorable to the project, a positive set of circumstances, a positive set of events, a risk that will have a positive impact on project objectives, or a possibility for positive changes. (PMI, 2008)

Organization – an organized body of people with a particular purpose, especially a business, society, association, etc. (OXFORD UNIVERSITY PRESS, 2016)

Practice – a specific type of professional or management activity that contributes to the execution of a process and that may employ one or more techniques and tools. (PMI, 2008)

Procurement – the act of buying. (COLLINS DICTIONARY, 2016)

Product – an artifact that is produced, is quantifiable, and can be either an end item in itself or a component item. (PMI, 2008)

Program – a group of related projects managed in a coordinated way to obtain benefits and control not available from managing them individually. (PMI, 2008)

Programmatic aspect – non-technical constraints.

Project – a temporary endeavor undertaken to create a unique product, service, or result. (PMI, 2008)

Realization – system realization represent the systems engineering activities related to the system implementation, integration, verification, and validation. (BKCASE EDITORIAL BOARD, 2013)

Requirement – matters that shall mandatorily be met.

Risk – an uncertain event or condition that, if it occurs, has a positive or negative effect on a project's objectives. (PMI, 2008)

Satellite – an artificial unmanned body orbiting the Earth. (LEY et al., 2009)

Space systems engineering – systems engineering effort applied to transform a set of needs into a space system solution.

Stakeholder – organization or person who have influence or is influenced by a system.

Statement of work – a narrative description or products, services, or results to be supplied. (PMI, 2008)

Subject – natural or manufactured object or phenomena that the payload will sense or interact with. (JON SELLERS et al., 2004)

Turnkey satellite – a complete satellite (i.e. platform and payload) that can be procured from the market with little or no customized modifications.

ATTACHMENT A - CATALOG OF REMOTE SENSING TURNKEY SATELLITES

This attachment presents a previous work done by the author of this dissertation for the Systems Engineering Office (LSIS) of the Laboratory of Integration and Testing (LIT) of Brazilian National Institute for Space Research (INPE). It consists in a catalog of remote sensing satellites, platforms, and their related launch vehicle services that several manufacturers offer on the market. This catalog was constructed public information obtained from manufacturers websites. Last update of the catalog was done in July, 2015.

AIRBUS DEFENCE & SPACE

Division of Airbus Group formed by combining the business activities of Cassidian, Astrium and Airbus Military. Europe's number one defense and space enterprise, the second largest space business worldwide and among the top ten global defence enterprises.

They offer:

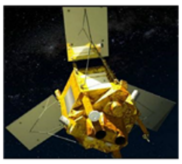
- -**Complete satellites** for several applications
- -**Platforms**
- -Observation Payloads (**Radar** and **Optical**)
- -**Launch services** on Ariane 5 rockets. Another launchers: Vega Small Launcher, Eurockot

Flight experience: Pléiades (50 cm colour images for military applications), Sentinel-1, Sentinel-2, Sentinel-3, Sentinel-4 (Radar imagery, disasters monitoring missions, meteorological missions), PAZ (SAR satellite), TeraSAR-X, Myriade, Astrobus-L, etc.

http://www.space-airbusds.com/en/thematic-list/?security
http://www.space-airbusds.com/en/thematic-list/?environment
http://www.space-airbusds.com/en/thematic-list/?access-to-space
http://www.defenceandsecurity-airbusds.com/en_US/web/guest/telescope-systems

AIRBUS DEFENCE & SPACE

AstroBus-L (AstroSat-250) (Astrium)



Payload Mass	100-1000 kg
Payload Power	100 W to several kW
Attitude	Side-looking up to 45 °
Orbit	400 to 900 km / Sun synchronous (at various LTAN) or non-sun synchronous
Designed Life	Up to 10 years
Flight Experience	SPOT-6, SPOT-7, SEOSat, Sentinel-2, EarthCARE, Kazakhstan HR imaging satellite

Related Launch Vehicle: None

http://www.iafastro.net/iac/archive/browse/IAC-11/B4/7/11348/
https://directory.eoportal.org/web/eoportal/satellite-missions/s/spot-6-7

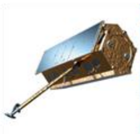
Myriade

Payload Mass	Up to 80 kg
Payload Dimensions	600 mm x 600 mm x 350 mm
Satellite Mass	130 kg (with payload)
Satellite Dimensions	600 mm x 600 mm x 800 mm or 600 mm x 600 mm x 500 mm
Satellite Power	60 W (permanent in SSO) / 200 W (peak)
Applications	Scientific missions, infrared imagery for military purposes, optical imagery, meterology, Earth observation
Stabilization Mode	3-axis
Attitude	Pointing Precision: < 5 x 10^{-3} ° / Pointing Stability: < 2 x 10^{-2} °
Propulsion	80 m/s / 1 N hydrazine thrusters (Tank capacity: 4,5 liters)
Communication	S-Band link for TM&TC compatible with CCSDS standard / TC rates 20 kbps / TM rates: 625 kbps (normal) & 16,8 Mbps (high rate)
Orbit	600-1000 km (Inclination from 20-98°)
Designed Life	2 years
Data Storage Capability	1 Gb (RAM) / 256 MB (flash memory) / 16 Gb solid state mass memory to store payload data (optional)
Flight Experience	DEMETER, PARASOL, Essaim, SPIRALE, Picard, AISAT-2ª, ELISA, SSOT, SARAL/Altika, TARANIS (2015), MICROSCOPE (2015), SMESE (proposed)

Related Launch Vehicle: None

http://smsc.cnes.fr/MYRIADE/GP_plateforme.htm
https://directory.eoportal.org/web/eoportal/satellite-missions/m/myriade

TerraSAR-X



Satellite Mass	1200 kg
Dimensions	5 m (Length) x 2,4 m (Diameter)
Applications	Environmental planning, land use and natural resource exploration, regional and urban development, catastrophe response and relief, insurance and risk, security and defence, and many more
Redundancy	SAR instrument elements are fully redundant
Communication	X-Band downlink through an antena mounted on a 3,3m long deployable boom (300 Mbps)
Orbit	514,8 km altitude at equator / Sun-synchronous
Designed Life	5 years
Antenna	SAR antenna dimensions: 4800 mm (Length) x 800 mm (Width) x 150 mm (Depth)
Payload Imaging Modes	High Resolution SpotLight, SpotLight, StripMap and ScanSAR (single or dual polarisation)
Imaging frequency band	X-band (9.65 GHz)
Imaging polarisations	Single: HH or VV (High Res. SpotLight, SpotLight, StripMap) Dual: HH + VV (High Res. SpotLight, SpotLight, StripMap) Dual: HH + HV (StripMap) Dual: VV or VH (StripMap) ScanSAR: HH or VV
Spatial Resolution	1-2 m (High Res. SpotLight), 2-4 m (SpotLight), 3-6 m (StripMap), 18,5 m (ScanSAR)
Swath	10 km (High Res. SpotLight), 10 km (SpotLight), 15-30 km (StripMap), 100 km (ScanSAR)
Incidence Angle	20-55 ° (High Res. SpotLight, SpotLight) / 20-45 ° (StripMap, ScanSAR)
Payload Data Memory	256 Gbit in a solid state mass memory unit (EOL)
Flight Experience	TerraSAR-X, TanDEM-X

Related Launch Vehicle: None

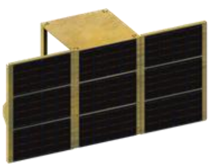
http://www.geoimage.com.au/satellite/TerraSar
http://www.ipi.uni-hannover.de/fileadmin/institut/pdf/roth.pdf
http://www.space-airbusds.com/en/programme/terrasar-x-zfr.html
http://www.dlr.de/Portaldata/1/Resources/forschung_und_entwicklung/missionen/terrasar_x/EUSAR-TX-Mission.pdf

Andrews Space is a small responsive integrator developing enabling systems for the emerging commercial space industry.

They offer:

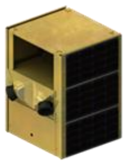
- **Complete small satellites** with high performance
- Small satellites **platforms**
- **Launch services** through their sister company Spaceflight.

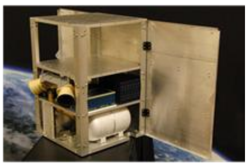
SENTRY 4000 PLATFORM:



Platform Dimensions	40 cm x 46 cm x 84 cm (stowed)
Platform Power	173 W (BOL at solar panels output)
Flight Experience	SCOUT
Price	$3500000 (starting price)

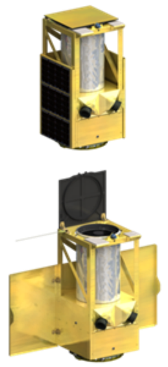
Related Launch Vehicle: Spaceflight solutions





http://andrews-space.com/systems/
http://andrews-space.com/sentry-bus
http://andrews-space.com/sentry4000/

SCOUT (based on SENTRY 4000 bus)



Payload Power	95 W (average)
Platform Mass	50-55 kg (with propellent)
Platform Dimensions	40 cm x 46 cm x 84 cm (stowed)
Platform Power	Batteries: 216 W-h, Li-Ion / Main Bus: 28 V
Applications	LEO imagery
Stabilization Mode	3-axis
Attitude	Pointing Knowledge: < 18 arcsec / Pointing Control: 0,05 ° (1σ) / Slew Rate: ~1 °/s / Position Knowledge: 10 m
Propulsion	Warm-Gas Butane
Communication	50 Mbps X-Band Payload Downlink / S-Band TM/TC Dowlink&Uplink
Orbit	450 km, Sunsynchronous
Designed Life	3 years
GSD	1 m
Spectral Bands	Panchromatic / Color
Other Features	Passive Thermal Control, Limited Heaters
Price	$5000000 (starting price)

Related Launch Vehicle: Spaceflight solutions

http://andrews-space.com/scout/
http://andrews-space.com/sentry-bus
http://andrews-space.com/sentry4000/

Former global aerospace, defense and commercial products company.

Merged with Orbital in February 2015. This information is not more available online

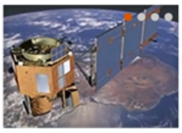
They offer:

- **Platforms** for earth observation
- **Optical** systems
- Others: Composite bus structures, towers and subsystems for housing, cable design, antennas, sensors, control systems, heat pipes, launch structures, thermal blankets and coatings, etc.

Flight experience: EO-1, THEMIS, ARTEMIS, ORS-1, EO-1, TacSat-3, Darpa Phoenix

Information obtained from (Dec. 2014):
http://www.atk.com/about/corporate-overview
http://www.atk.com/products-services/aerospace-group
http://www.atk.com/products-services/bus-structures-towers-subsystems
This links are not more available since the merge of Orbital and ATK.

Earth Observer-Spacecraft Bus (EO-SB)



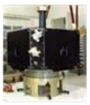
ATK merged with Orbital in February 2015). This information is not more available online, and is it not known if this platforms are still available from new OrbitalATK

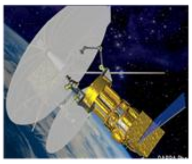
Payload Mass	236 kg
Payload Dimensions	1 m x 0,75 m x 1,5 m (external volume available for payload) / 280 mm x 232 mm x 180 mm (internal volume available for payload)
Payload Power	256 W (average at EOL)
Platform Mass	332 kg (without propellant)
Platform Power	Batteries: 50 Ah / Main Bus: 28 V ± 6 Vdc (unregulated)
Applications	Earth Observation
Stabilization Mode	3-axis (zero momentum)
Attitude	Pointing Knowledge: 36 arcsec (3σ) / Poiting Accuracy: 60 arcsec (3σ) / Pointing Stability (Jitter): 0,3 arcsec/s / Slew Rate: 15-60°/min
Propulsion	1 tank / 4 thrusters / propellant Capacity 22,3 kg / Delta V: > 100 m/s
Communication	Downlink: S-Band 2 Mbps or X-Band 105 Mbps (optional) / Dowlink Formats: CCSDS/STDN, DSN, TDRSS / Uplink: S-Band 2 kbps
OBDH	MIL-STD-1773 (1553 optional)
Thermal	0-40 °C
Orbit	400-900 km / Inclination: 0-99 °
Designed Life	1,5 years
Data Storage Capability	1,8 Gb
Heritage Missions	EO-1
Delivery Schedule	36 months (Ready for Launch)

Related Launch Vehicle: Delta II 7320-10 DPAF. Also compatible with Taurus and Athena launch vehicles

http://www.atk.com/products-services/aerospace-group
http://www.atk.com/products-services/earth-observer-spacecraft-bus-eo-sb

Small Satellite Buses





	A100	A150	A200	A500
Payload Mass	Up to 15 kg	Up to 60 kg	Up to 200 kg	200-500 kg
Payload Power	50 W (average)	75 W (average)	150-500 W (average)	500-2000 W (average)
Mission Class	Class B/C/D	Class B/C/D	Class B/C/D	Class A/B
Redundancy	Single string to selective	Single string to selective	Single string to selective	Block to Selective
Attitude	Pointing Knowledge: 0,05-1,0 ° / Pointing Accuracy: 0,2 °	Pointing Knowledge: 0,008 ° / Pointing Accuracy: 0,05 °	Pointing Knowledge: 0,004 ° / Pointing Accuracy: 0,05 °	Pointing Knowledge: 0,01 ° / Pointing Accuracy: 0,05 °
Propulsion	200 m/s	150 m/s	300 m/s	Up to 1000 m/s
Designed Life	1-5 years	1-5 years	1-5 years	2-7 years
Flight Experience	THEMIS, ARTEMIS		ORS-1, EO-1, TacSat-3	Darpa Phoenix

Related Launch Vehicle: None

ATK merged with Orbital in February 2015). This information is not more available online, and is it not known if this platforms are still available from new OrbitalATK

http://www.atk.com/products-services/small-satellite-buses
http://cms.atk.com/SiteCollectionDocuments/ProductsAndServices/ATK%20500%20Data%20Sheet.pdf
http://cms.atk.com/SiteCollectionDocuments/ProductsAndServices/ATK%20200%20Data%20Sheet.pdf
http://cms.atk.com/SiteCollectionDocuments/ProductsAndServices/ATK%20150%20Data%20Sheet.pdf
http://cms.atk.com/SiteCollectionDocuments/ProductsAndServices/ATK%20100%20Rev%20Data%20Sheet.pdf
http://cms.atk.com/SiteCollectionDocuments/ProductsAndServices/A-Series%20Satellites%20Data%20Sheet%202014.pdf

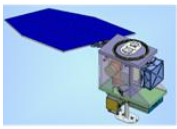
Ball Aerospace & Technologies Corp is a respected leader in providing integrated buses and precision spacecraft. Also, industry leaders in remote sensing and optics.

They offer:

- **Complete satellites** for commercial telecommunications, scientific and environmental applications. Focused on space systems for military and scientific uses
- **Optical** and **Radar** Payloads
- **Platforms**
- **Launch services**
- Other components (attitude sensor, mechanisms and laser applications, etc.)

http://www.ballaerospace.com/page.jsp?page=95
http://www.ballaerospace.com/page.jsp?page=13
http://www.ballaerospace.com/page.jsp?page=14

Ball Configurable Platform 50 (BCP 50)

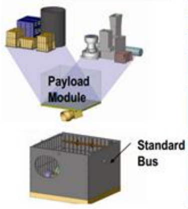


Payload Mass	30 kg
Payload Dimensions	33 cm x 30 cm x 55 cm (chamfered for Centaur ABC option)
Payload Power	> 100 W (average - best case orbit) / 30 W (average – worst case)
Payload Interface	RS-422 (up to two independente payloads) / Discrete inputs and outputs, analogs
Platform Mass	≤ 80 kg
Platform Power	Main Bus: 28 V ± 6 Vdc
Applications	Scientific, technology development, and risk reduction payloads
Stabilization Mode	3-axis
Attitude	Pointing modes: nadir, ground target tracking, intertial point, payloads sun point, safe / Attitude Knowledge: 0,03 ° (3σ) / Attitude Control: 0,03-0,10 ° (3σ) depending on mode
Propulsion	
Communication	L-Band Uplink, S-Band Downlink, 2 kbps Uplink Command Rate, 1 Mbps Downlink Telemetry Rate
OBDH	16 Gb storage, Up to 2 Mbps payloads data handling for each payloads
Orbit	400-900 km, inclination: 0-98,8 °
Other Features	Deployable de-orbit drag device (optional), Nearly hemispherical field of view for payloads

Related Launch Vehicle: ESPA, ESPA Grande, Centaur Aft Bulkhead Carrier, Minotaur I, Minotaur IV, Pegasus

http://www.ballaerospace.com/page.jsp?page=95
http://www.ballaerospace.com/file/media/D3103_BC__50%20ds_0714.pdf

Ball Configurable Platform 100 (BCP 100)



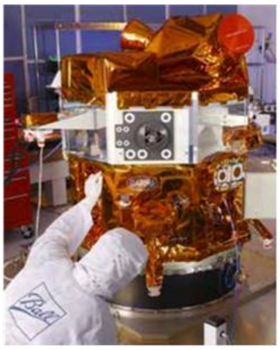
Payload Mass	70 kg
Payload Dimensions	0,14 m^3 for ESPA compatibility (can be increased for other launch vehicles)
Payload Power	> 200 W (average - best case orbit) / 100 W (average – worst case)
Payload Interface	RS-422 (up to 4 independente payloads) / 8 Digital inputs and 8 Digital outputs bi-level discretes per payloads / 8 analog channels per payloads for health and status
Platform Mass	≤ 180 kg for ESPA compatibility (can be increased for other launch vehicles)
Platform Dimensions	≤ 60,9 x 71,1 x 96,5 cm for ESPA compatibility (can be increased for other launch vehicles)
Platform Power	Main Bus: 28 V ± 6 Vdc
Applications	Scientific, technology development and risk reduction payloads
Stabilization Mode	3-axis
Attitude	Pointing modes: nadir, ground target tracking, intertial point, payloads sun point, safe / Attitude Knowledge: 0,03 ° (3σ) / Attitude Control: 0,03-0,10 ° (3σ) depending on mode (enhanced options available)
Propulsion	Optional for green propellant or hydrazine
Communication	L-Band Uplink, S-Band Downlink, 2 kbps Uplink Command Rate, 2 Mbps Downlink Telemetry Rate (5 Mbps option)
OBDH	2 GB storage (expandable with flash memory), Up to 2 Mbps payloads data handling for each payloads
Orbit	400-850 km, inclination: 0-98 °
Designed Life	1 year @ 0,93 / 3 years @ 0,81 / 5 years @ 0,71 (reliability)
Other Features	Unobstructed hemispherical field of view for payloads, 100 W payloads heat rejection, interface temperature -20 ° C to +50 ° C
Flight Experience	DARPASAT (1994), STPSat-2 (2010), STPSat-3 (2013), GPIM (2015)
Delivery Schedule	24 months

Related Launch Vehicle: Delta IV and Atlas V (on the secondary Payload Adapter (ESPA)), Minotaur IV, Pegasus, Falcon 9 and Falcon Heavy

http://www.ballaerospace.com/page.jsp?page=95
http://www.ballaerospace.com/file/media/D3072_BCP100%20ds_1_14.pdf

Ball Configurable Platform 300 (BCP 300)

WISE satellite
(Space Observation Mission)



Orbital Express NEXTSAT Satellite
(Technology Demonstration Mission)

http://www.ballaerospace.com/file/media/D1920_BCP%20SC_9_14_2.pdf

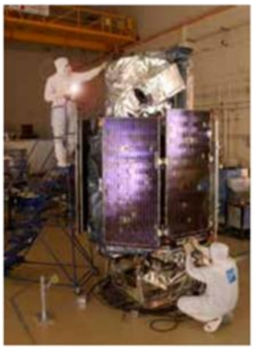
Ball Configurable Platform 2000 (BCP 2000)

Suomi NPP Satellite
(Meteorological Mission)

Kepler Satellite
(Telescope Mission)

SBSS Satellite
(Space Objects Tracking Mission)

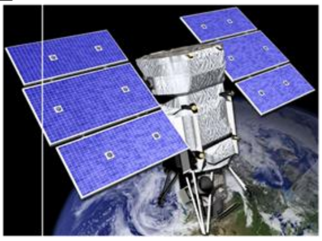
QuickBird Satellite
(Remote Sensing Mission)
Spatial Resolution: PAN (61 cm) & MS (2,5 m)
Swath: 14-34 km
Orbit: 450 km (98 °, sunsynchronous)



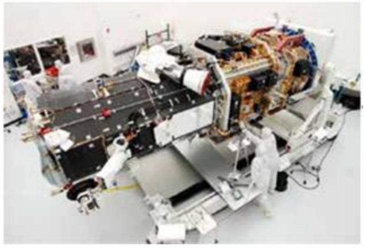
http://www.ballaerospace.com/page.jsp?page=77
http://www.ballaerospace.com/file/media/D1920_BCP%20SC_9_14_2.pdf

Ball Configurable Platform 5000 (BCP 5000)

WorldView-1 Satellite
(Remote Sensing Mission)
Spatial Resolution: PAN (50 cm)
Orbit: 450 km



WorldView-2 Satellite
(Remote Sensing Mission)
Spatial Resolution: PAN (61 cm) & MS (2,5 m)
Swath: 14-34 km
Orbit: 450 km (98 °, sunsynchronous)



http://www.ballaerospace.com/page.jsp?page=77
http://www.ballaerospace.com/file/media/D3088_WV3_06_14.pdf
http://www.ballaerospace.com/file/media/D1848%20WV2_11_13.pdf
http://www.ballaerospace.com/file/media/D1920_BCP%20SC_9_14_2.pdf
http://www.ballaerospace.com/file/media/D1444_WorldView_03_08_low.pdf

Boeing is the world's largest aerospace company and leading manufacturer of commercial jetliners and defense, space and security systems.
Boeing Defense, Space & Security (BDS) is one of the largest, most experienced companies in the markets it serves around the world.

They offer:

- -**Complete satellites** for commercial telecommunications, scientific and environmental applications. Focused on space systems for military and scientific uses
- -**Payloads**
- -**Platforms**
- -**Launch services** through Delta launch vehicles (Delta II and Delta IV)

http://www.boeing.com/boeing/companyoffices/aboutus/brief.page
http://www.boeing.com/boeing/companyoffices/aboutus/brief/bds.page?

Boeing 502 Phoenix

Payload Mass	Up to 250 kg
Payload Dimensions	1,0 m x 1,0 m x 1,5 m
Payload Power	> 280 W continuous / Up to 600 W intermittent (at 900W platform power) / Higher options available
Payload Interface	SpaceWire, RS422, MIL-STD-1553
Platform Mass	500-1000 kg (with propellant)
Platform Dimensions	1,25 m x 1,25 m x 1 m (tall)
Platform Power	1500 W (Total, BOL) / Li-Ion Batteries: > 90 A-hr (EOL)
Applications	Communications, intelligence, surveillance and reconnaissance, missile defense, Earth Science & weather, planetary Science, technology demonstrations
Stabilization Mode	3-axis
Attitude	Pointing Accuracy Knowledge: 0,003 °/axis (3σ) / Pointing Accuracy Control: 0,010 °/axis (3σ) / Control Characteristics: 6-DOF (Degrees of Freedom), zero momentum, high agility and stablity
Propulsion	> 400 m/s (at 750 kg spacecraft mass) / 1 N, 4 N, 22 N (configurable up to 16 thrusters)
Orbit	GEO/MEO/LEO orbits
Designed Life	Up to 10 years
Other Features	Plug and play architecture
Flight Experience	HySpec IQ (2 satellites planned for 2018 with more than 200-bands hyperspectral payload)

Related Launch Vehicle: Falcon 9 (dual launch), dedicated Minotar, Taurus to LEO, Rideshare EELV to GEO

http://www.boeing.com/boeing/defense-space/space/bss/factsheets/502/phoenix.page?
http://www.boeing.com/assets/pdf/defense-space/space/bss/factsheets/502/phoenix_502_product_card.pdf

中国空间技术研究院
China Academy of Space Technology

Through 40-year development, it has become the main development base for space technology and products in China and the most powerful backbone strength for China's space endeavor.

They offer:

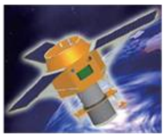
- -**Complete satellites**
- -**Platforms**
- -**Optical** payloads
- -**Launch services** (launch site & launch vehicles) through LEO launch vehicles: LM-2C, LM-2D, LM-

Flight experience: CBERS-1, CBERS-2, CBERS-2B, CBERS-3, CBERS-4, ZY-2-01, ZY-2-02, ZY-2-03, VRSS-1, HY-1, HY-1B, HY-2, HJ-1A, HJ-1B, HJ-1C

http://www.cast.cn/CastEn/Class.asp?ClassID=70
http://www.cgwic.com/LaunchServices/LaunchVehicle/LM2C.html

中国空间技术研究院
China Academy of Space Technology

CAST 3000 Platform



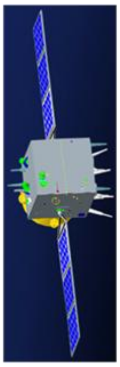
Payload Mass	> 380 kg
Platform Mass	300-400 kg
Platform Power	945-1148 W (EOL at the solar array output)
Applications	Earth observation, technological demonstration, scientific exploration, Earth environmental exploration, formation flight and networking, meteorological research and application, communications, navigation. It is mainly applicable to high resolution optical imaging and radar imaging missions
Stabilization mode	3-axis
Attitude	Pointing mode: Earth pointing or inertial space pointing / Attitude Maneuver Ability: ± 45 ° (along roll and pitch axes) / Stereo speed: 5 ° within 11 s, 15 ° within 16 s, 30 ° within 21 s, 45 ° within 25 s, 60 ° within 30 s, 90 ° within 35 s (times include stabilization time along roll and pitch axes) / Attitude Measurement Accuracy: < 0,001° (3σ) / Attitude Pointing Accuracy: < 0,05 °/s (3σ) / Attitude Stability: < 0,0005 °/s (3σ)
Propulsion	Hydrazine propellant 32,5-130 kg (optional)
Orbit	LEO, MEO or HEO
Communications	S/X band data transmission
Designed Life	> 5 years
Flight Experience	Under development

Related Launch Vehicles: Long March Series

http://www.cast.cn/CastEn/Show.asp?ArticleID=39325

中国空间技术研究院
China Academy of Space Technology

CAST 2000 Platform



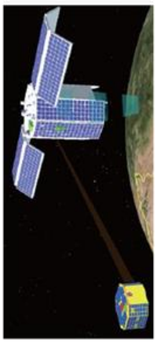
Payload Mass	300-600 kg
Platform Mass	200-400 kg
Platform Power	≥1000W(BOL), ≥900 W(EOL) (at the solar array output)
Applications	Earth observation, technological demonstration, scientific exploration, Earth environmental exploration, formation flight and networking, meteorological research and application, communications, navigation.
Stabilization mode	3-axis
Attitude	Attitude Measurement Accuracy: ≤ 0,03 ° (3σ) / Attitude Control Accuracy: ≤ 0,1 ° (3σ) / Attitude Stability: < 0,001 °/s (3σ) / Orbit maneuver and maintenance capability
Orbit	LEO, MEO or HEO
Communications	S-Band TT&C sub-system, X band data transmission
Designed Life	> 3 years
Flight Experience	SJ-5, HY-1A, TC-1, TC-2, SJ-6B, ShiyanSat-2

Related Launch Vehicles: Long March Series

http://www.cast.cn/CastEn/Show.asp?ArticleID=39324
http://www.cgwic.com/In-OrbitDelivery/RemoteSensingSatellite/CAST2000.html

中国空间技术研究院
China Academy of Space Technology

CAST 1000 Platform



	CAST-1000A	CAST-1000B	CAST-1000C
Payload Mass	5-15 kg	20-60 kg	70-120 kg
Platform Mass	25-50 kg	80-160 kg	180-250 kg
Platform Power	> 16 W (average) / > 30 W (peak) / Li-Ion: 10/15 Ah	> 100 W (average) / > 250 W (peak) / Li-Ion: 10 Ah	> 260 W (average) / > 800 W (peak) / Li-Ion: 20/30 Ah
Applications	Earth observation, atmospheric exploration, electromagnetic exploration, technological demonstration, on-orbit servisse, LEO communication, supporting satellite constellation and formation flying.		
Stabilization mode	3-axis or spin	3-axis	3-axis
Attitude	Pointing Accuracy: 1-5 ° / Stability: 0,2 °/s	Pointing Accuracy: 0,6 ° / Stability: 0,05 °/s	Pointing Accuracy: 0,1 ° / Stability: 0,003 °/s / Agility: 35 ° in roll
Propulsion	Cold gas, 0,02N thruster	Hydrazine / 0,2 N thruster / 25 m/s	Hydrazine / 1 N thruster / 100 m/s
Orbit	Inclination ≥ 30 ° (including SSO), Altitude 400-1200 km		
Communications	Frequency: S-Band / Uplink: 2-64 kbps / Dowlink: 4096-16384 bps		
Designed Life	3-5 years		
Flight Experience	SJ-9A, SJ-9B, Olympic-Sat		

Related Launch Vehicles: Long March Series

http://www.cast.cn/CastEn/Show.asp?ArticleID=39323

COM DEV INTERNATIONAL

COM DEV International Ltd. is a global designer and manufacturer of space hardware and systems

They offer:

- **Complete microsatellites**
- **Platforms** for earth observation
- **Optical** payloads and payloads for space surveillance
- Technologies and subsystems for communications, space science and remote sensing

Flight experience: Viking, Freja, Radarsat, Terra, SciSat, the ISS, Genesis, Jason-1, FUSE, Cloudsat, Envisat, etc.

http://www.comdev.ca/corporate
http://www.comdev.ca/products-capabilities/

COM DEV INTERNATIONAL

M3MSat (based on the AIM-Advanced Integrated Microsatellite Bus)

Payload Mass	25 kg
Payload Dimensions	53,5 cm x 54,5 cm x 28,5 cm
Payload Power	50-60 % of the platform power
Payload Interface	RS4-85
Satellite Mass*	85 kg
Satellite Dimensions*	60 cm x 60 cm x 80 cm
Platform Power	80 to 120 W (average)
Applications	Adaptable multi-mission platform for microspace solutions
Stabilization Mode	3-axis
Redundancy	A-side/B-side redundancy
Attitude	Fine pointing control (with reaction wheels) / Pointing Accuracy: < 5 ° / Slew: 180 ° in less than 15 minutes
Propulsion	None
Communication	Redundant S-Band links for commanding, telemetry and payload data (C-Band High Speed Downlink optional for payload data) / CCSDS and ECSS communication standards / Uplink: 4 kbps / Downlink: 32 kbps to 6,25 Mbps
OBDH	CAN bus
Orbit	600-850 km
Designed Life	1-2 years
Flight Experience	M3MSat (launch with an unceirtain status)

* M3MSat values

Related Launch Vehicle: None

http://www.comdev.ca/products-capabilities/missions
https://directory.eoportal.org/web/eoportal/satellite-missions/m/m3msat

Israel Aerospace Industries (IAI) is globally recognized leader in the development and production of systems for the defense and commercial markets.

They offer:

-**Complete satellites** for several applications
-Observation Payloads (**Radar** and **Optical**)
-**Launch services** with launch vehicles: Shavit, PSLV, PSLV-C10

http://www.iai.co.il/2013/10285-en/CompanyInfo-CompanyProfile.aspx
http://www.iai.co.il/2013/35083-en/BusinessAreas_SpaceSystems_ObservationSatellites.aspx

TecSAR Satellite (based on IMPS II bus)

Satellite Mass	295 kg
Applications	Remote sensing
Stabilization Mode	3-axis
Orbit	Apogee: 580 km – Perigee: 450 km – Inclination: 41 °
Payload Imaging Modes	Spot (spot imaging by mechanical steering), Strip (strips widths according to required resolution), Scan (wide area coverage using electronic beam steering), Mosaic (coverage of large area with high resolution using mechanical and electronic steering)
Imaging frequency band	X-Band
Spatial Resolution	1 m

Related Launch Vehicle: PSLV-C10 (India)

http://www.iai.co.il/2013/35083-39439-en/IAI.aspx
http://www.aerospace-technology.com/projects/tecsar-satellite/
http://www.iai.co.il/2013/35083-en/BusinessAreas_SpaceSystems_ObservationSatellites.aspx

OptSat 3000 (based on IMPS II bus)

Platform Mass	400 kg
Applications	Remote sensing
Stabilization Mode	3-axis
Designed Life	> 6 years
GSD	1 m
Spectral Bands	Panchromatic & Multi-spectral
Flight Experience	Planned launch for 2016

Related Launch Vehicle: Vega

http://www.iai.co.il/2013/35083-39441-en/IAI.aspx
http://www.iai.co.il/2013/35083-en/BusinessAreas_SpaceSystems_ObservationSatellites.aspx

OptSat 2000 & OpSat 1000

Platform Mass	250 kg
Applications	Remote sensing
Stabilization Mode	3-axis
Flight Experience	Ofeq 3, Ofeq-4, Ofeq-5, Ofeq-6, Ofeq-7, Ofeq-8, Ofeq-9, EROS-A1, EROS-2

Related Launch Vehicle: None

http://www.iai.co.il/2013/35083-39442-en/IAI.aspx
http://www.iai.co.il/2013/35083-39444-en/IAI.aspx
http://www.iai.co.il/2013/35083-en/BusinessAreas_SpaceSystems_ObservationSatellites.aspx

KARI Korea Aerospace Research Institute

Government-funded research institute leading Korean aerospace development.

They offer:

-**Complete satellites** for commercial telecommunications, scientific and environmental applications. Focused on space systems for military and scientific uses
-**Payloads**
-**Platforms**
-**Launch services**

http://eng.kari.re.kr/sub04_01
http://ksp.kari.re.kr/html/korean/04_sub/sub04.html
http://ksp.kari.re.kr/html/korean/04_sub/sub04_01_01.html

KSP-100 Series Platform

Payload Mass	40 kg
Payload Dimensions	0,5 m x 0,5 m x 0,3 m (H)
Payload Power	30 W (orbit average)
Platform Mass	80 kg (without propellant)
Platform Dimensions	0,6 m x 0,6 m x 0,9 m (H) (stowed) / 2,2 m x 0,6 m x 0,9 m (H) (deployed)
Platform Power	200 W / Batteries: 18 Ah, Li-Ion / Main Bus: 28 V (unregulated)
Applications	Technology acquisition and practical applications
Stabilization Mode	3-axis with reaction wheels and magnetic torquers
Attitude	Pointing Accuracy: 0,2 ° (3σ) / Pointing Stability: 0,01 °/s (3σ) / Pointing Agility: 1,0 °/s
Communication	160 Mbps X-Band Data Downlink / S-Band Telemetry and Telecommand Downlink-Uplink
OBDH	SpaceWire, UART, MIL-STD-1553B
Thermal	Primarily Passive Type
Orbit	LEO: 500-700 km
Designed Life	5 years
Data Storage Capability	128 Gb
Heritage	STSAT series
Delivery Schedule	30 months

Related Launch Vehicle: None. Piggiback launch is possible

ksp.kari.re.kr/download/satellite/ksp-100.pdf
http://ksp.kari.re.kr/html/korean/04_sub/sub04_01_01_02.html

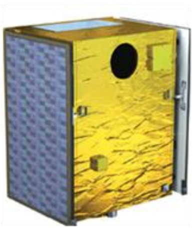
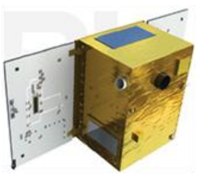
KSP-100 Series Platform with Payload

	KSP-100A	KSP-100B	KSP-100C	KSP-100D
Payload Type	Electro-Optical Imager	Electro-Optical Imager	Hyper-spectral Imager	Hyper-spectral Imager
Payload Mass	18 kg	22 kg	12 kg	35 kg
Payload Power	70 W (peak) / 25 W (average)	100 W (peak) / 30 W (average)	20 W (peak) / 10 W (average)	60 W (peak) / 20 W (average)
Applications	Disaster monitoring, land management and security	Urban planning and disaster monitoring	Agriculture, forest and maritime monitoring and natural resources management and planning	Natural resources management and environmental monitoring
Communication	45 Mbps Data Dowlink	45 Mbps Data Dowlink	160 Mbps Data Downlink	1 Mbps Data Downlink
Orbit	528 km			
GSD	PAN: 10 m	PAN: 10 m / MS: 40 m	30 m	24 km
Swath Width	> 30 km	> 30 km	> 30 km	> 2000 km
Spectral Resolution			10 nm	0,5 nm
Designed Life	5 years			
Data Storage Capability	16 Gb	16 Gb	128 Gb	1 Gb
Delivery Schedule	36 months			

Related Platform: KSP-100

http://ksp.kari.re.kr/download/Satellite/KSP-100A.pdf
http://ksp.kari.re.kr/download/Satellite/KSP-100B.pdf
http://ksp.kari.re.kr/download/Satellite/KSP-100C.pdf
http://ksp.kari.re.kr/download/Satellite/KSP-100D.pdf
http://ksp.kari.re.kr/html/korean/04_sub/sub04_01_01_02.html

KSP-200 Series Platform

Payload Mass	70 kg
Payload Dimensions	0,9 m x 0,9 m x 0,6 m (H)
Payload Power	120 W (orbit average)
Platform Mass	140 kg (without propellant)
Platform Dimensions	1,0 m x 1,0 m x 1,5 m (H) (stowed) / 3,0 m x 1,0 m x 1,5 m (H) (deployed)
Platform Power	450 W / Batteries: 31,5 Ah, Li-Ion / Main Bus: 28 V (unregulated)
Applications	Technology acquisition and practical applications
Stabilization Mode	3-axis with reaction wheels and magnetic torquers
Attitude	Pointing Accuracy: 0,13 ° (3σ) / Pointing Stability: 0,007 °/s (3σ) / Pointing Agility: 1,0 °/s
Communication	320 Mbps X-Band Data Downlink / S-Band Telemetry and Telecommand Downlink-Uplink
OBDH	SpaceWire, UART, MIL-STD-1553B
Thermal	Primarily Passive Type
Orbit	LEO: 500-700 km
Designed Life	5 years
Data Storage Capability	256 Gb
Heritage	STSAT series
Delivery Schedule	30 months

Related Launch Vehicle: Rockot, Minotaur IV, VEGA

http://ksp.kari.re.kr/download/satellite_ksp_200/ksp-200.pdf
http://ksp.kari.re.kr/html/korean/04_sub/sub04_01_01_03.html

KSP-200 Series Platform with Payload (1/2)

	KSP-200A	KSP-200B	KSP-200C	KSP-200D
Payload Type	Electro-Optical Imager / IR Sensor	Electro-Optical Imager	Electro-Optical Imager	Electro-Optical Imager / IR Sensor
Payload Mass	37 kg	27 kg	32 kg	45 kg
Payload Power	150 W (peak) / 50 W (average)	145 W (peak) / 70 W (average)	175 W (peak) / 80 W (average)	255 W (peak) / 120 W (average)
Applications	Multi-purpose application	Disaster monitoring, cartography and water management	Disaster monitoring, cartography and water management	Monitoring of disasters, natural resources, maritime and the environment
Communication	45 Mbps Data Downlink	160 Mbps Data Downlink	160 Mbps Data Downlink	160 Mbps Data Downlink
Orbit	528 km			
GSD	PAN: 10 m / MS: 40 m / IR: 100 m	PAN: 5 m	PAN: 5 m / MS: 20 m	PAN: 5 m / MS: 20 m / IR: 50 m
Swath Width	> 30 km	> 25 km	> 25 km	> 25 km
Designed Life	5 years			
Data Storage Capability	16 Gb	64 Gb	64 Gb	64 Gb
Delivery Schedule	36 months			

Related Platform: KSP-200

http://ksp.kari.re.kr/download/satellite_ksp_200/ksp-200a.pdf
http://ksp.kari.re.kr/download/satellite_ksp_200/ksp-200b.pdf
http://ksp.kari.re.kr/download/satellite_ksp_200/ksp-200c.pdf
http://ksp.kari.re.kr/download/satellite_ksp_200/ksp-200d.pdf
http://ksp.kari.re.kr/html/korean/04_sub/sub04_01_01_03.html

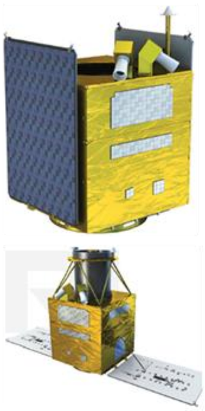
KSP-200 Series Platform with Payload (2/2)

	KSP-200E	KSP-200F	KSP-200G	KSP-200H
Payload Type	Electro-Optical Imager	Electro-Optical Imager	Multi-spectral Imager	Hyper-spectral Imager
Payload Mass	41 kg	45 kg	55 kg	22 kg
Payload Power	190 W (peak) / 80 W (average)	240 W (peak) / 90 W (average)	80 W (peak) / 60 W (average)	40 W (Peak) / 30 W (orbit)
Applications	Disaster monitoring, security and surveillance	Disaster monitoring, security and surveillance, urban and infrastructure planning	Disaster monitoring, natural resources monitoring, agriculture and forestry management	Monitoring natural resources, agriculture, forestry and the environment
Communication	160 Mbps Data Downlink	160 Mbps Data Downlink	5 Mbps Data Downlink	320 Mbps Data Downlink
Orbit	528 km			
GSD	PAN: 2,5 m	PAN: 2,5 m / MS: 10 m	1 km	20 m
Swath Width	> 15 km	> 15 km	> 1000 km	> 40 km
Spectral Bands			8 bands	
Spectral Resolution				10 nm
Designed Life	5 years			
Data Storage Capability	128 Gb	128 Gb	4 Gb	256 Gb
Delivery Schedule	36 months			

Related Platform: KSP-200

http://ksp.kari.re.kr/download/satellite_ksp_200/ksp-200e.pdf
http://ksp.kari.re.kr/download/satellite_ksp_200/ksp-200f.pdf
http://ksp.kari.re.kr/download/satellite_ksp_200/ksp-200g.pdf
http://ksp.kari.re.kr/download/satellite_ksp_200/ksp-200h.pdf
http://ksp.kari.re.kr/html/korean/04_sub/sub04_01_01_03.html

KSP-300 Series Platform



Payload Mass	95 kg
Payload Dimensions	1,0 m x 1,0 m x 0,4 m (H) (internal) / 1,1 m x 0,8 m x up to LV fairing limitation (external)
Payload Power	150 W (average)
Platform Mass	220 kg (without propellant)
Platform Dimensions	1,2 m x 1,2 m x 1,4 m (H) (stowed) / 4,5 m x 1,2 m x 1,4 m (H) (deployed)
Platform Power	600 W / Batteries: 26 Ah, Li-Ion / Main Bus: 50 V (unregulated)
Applications	Practical application with baseline performance
Stabilization Mode	3-axis with reaction wheels and magnetic torquers
Attitude	Pointing Accuracy: 0,13 ° (3σ) / Pointing Stability: 0,007 °/s (3σ) / Pointing Agility: 1,0 °/s
Propulsion	20 kg Propellant Capacity / 1 N x 4 Thrusters / 30 L Hydrazine mono-propellant tank
Communication	320 Mbps X-Band Data Downlink / S-Band Telemetry and Telecommand Downlink-Uplink
OBDH	SpaceWire, UART, MIL-STD-1553B
Thermal	Primarily Passive Type
Orbit	LEO: 500-700 km
Designed Life	5 years
Data Storage Capability	256 Gb
Heritage	STSAT series
Delivery Schedule	30 months

Related Launch Vehicle: Rockot, Minotaur IV, VEGA

http://ksp.kari.re.kr/download/Satellite/ksp-300.pdf
http://ksp.kari.re.kr/html/korean/04_sub/sub04_01_01_04.html

KSP-300 Series Platform with Payload

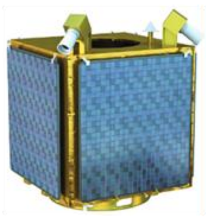
	KSP-300A	KSP-300B	KSP-300C	KSP-300D
Payload Type	Electro-Optical Imager / IR Sensor	Multi-spectral Imager	Hyper-spectral Imager	Hyper-spectral Imager
Payload Mass	59 kg	90 kg	95 kg	90 kg
Payload Power	330 W (peak) / 150 W (average)	100 W (peak) / 75 W (average)	190 W (peak) / 100 W (average)	170 W (peak) / 100 W (average)
Applications	Disaster monitoring, security and surveillance, urban and infrastructure planning and wild fire detection	Natural resources monitoring, agriculture and forestry mapping, and disaster monitoring	Natural resources monitoring, precision agriculture and forestry mapping, and disaster monitoring	Wide area natural resources monitoring, agriculture and forestry mapping, and disaster monitoring
Communication	160 Mbps Data Downlink	5 Mbps Data Downlink	320 Mbps Data Downlink	5 Mbps
Orbit	528 km			
GSD	PAN: 2,5 m / MS: 10 m / IR: 25 m	500 m	5 m	13 km
Swath Width	> 15 km	> 500 km	> 10 km	> 2000 km
Spectral Bands		8 bands		
Spectral Resolution			10 nm	0,5 nm
Designed Life	5 years			
Data Storage Capability	128 Gb	4 Gb	256 Gb	4 Gb
Delivery Schedule	36 months			

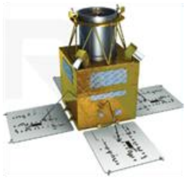
Related Platform: KSP-300

http://ksp.kari.re.kr/download/Satellite/ksp-300a.pdf
http://ksp.kari.re.kr/download/Satellite/ksp-300b.pdf
http://ksp.kari.re.kr/download/Satellite/ksp-300c.pdf
http://ksp.kari.re.kr/download/Satellite/ksp-300d.pdf
http://ksp.kari.re.kr/html/korean/04_sub/sub04_01_01_04.html

KARI Korea Aerospace Research Institute

KSP-500 Series Platform





Payload Mass	180 kg
Payload Dimensions	1,2 m x 1,2 m x 0,4 m (H) (internal) / 1,3 m x 1,0 m x up to LV fairing limitation (external)
Payload Power	250 W (average)
Platform Mass	330 kg (without propellant)
Platform Dimensions	1,4 m x 1,4 m x 1,6 m (H) (stowed) / 3,8 m x 3,8 m x 1,6 m (H) (deployed)
Platform Power	1000 W / Batteries: 45 Ah, Li-Ion / Main Bus: 50 V (unregulated)
Applications	Practical applications requiring high performance and agility
Stabilization Mode	3-axis with reaction wheels and magnetic torquers
Attitude	Pointing Accuracy: 0,015 ° (3σ) / Pointing Stability: 0,004 °/s (3σ) / Pointing Agility: 1,0 °/s
Propulsion	30 kg Propellant Capacity / 1 N x 8 Thrusters / 37 L Hydrazine mono-propellant tank
Communication	320 Mbps X-Band Data Downlink / S-Band Telemetry and Telecommand Downlink-Uplink
OBDH	SpaceWire, UART, CAN, MIL-STD-1553B
Thermal	Primarily Passive Type
Orbit	LEO: 500-700 km
Designed Life	7 years
Data Storage Capability	256 Gb
Heritage	KOMPSAT series
Delivery Schedule	38 months

Related Launch Vehicle: Rockot, Minotaur IV, VEGA

http://ksp.kari.re.kr/download/satellite/ksp-500.pdf
http://ksp.kari.re.kr/html/korean/04_sub/sub04_01_01_05.html

KARI Korea Aerospace Research Institute

KSP-500 Series Platform with Payload

	KSP-500A	KSP-500B	KSP-500C	KSP-500D
Payload Type	Electro-Optical Imager	Electro-Optical Imager	Electro-Optical Imager / IR Sensor	X-Band SAR
Payload Mass	117 kg	123 kg	165 kg	100 kg
Payload Power	240 W (peak) / 90 W (average)	325 W (peak) / 100 W (average)	380 W (peak) / 200 W (average)	1600 W (peak) / 250 W (average)
Applications	High accuracy mapping, security and surveillance.	Surveillance, urban planning, disaster monitoring, construction of geographic information system and cartography	Security and surveillance, wild fire detection, urban planning, disaster monitoring, construction of geographic information systems and cartography	High accuracy mapping, security and surveillance
Communication	320 Mbps Data Downlink	320 Mbps Data Downlink	320 Mbps Data Downlink	320 Mbps Data Downlink
Orbit	528 km	528 km	528 km	550 km
GSD	PAN: 1 m	PAN: 1 m / MS: 4 m	PAN: 1m / MS: 4 m / IR: 10 m	1 m (Spot) – 8 m (Scan)
Incidence Angle				20-55 °
Swath Width	> 15 km	> 15 km	> 15 km	Spot: 5 km / Strip: 30 km / Scan: 100 km
Designed Life	7 years			
Data Storage Capability	256 Gb	256 Gb	256 Gb	256 Gb
Delivery Schedule	48 months			

Related Platform: KSP-500

http://ksp.kari.re.kr/download/Satellite/ksp-500A.pdf
http://ksp.kari.re.kr/download/Satellite/ksp-500B.pdf
http://ksp.kari.re.kr/download/Satellite/ksp-500C.pdf
http://ksp.kari.re.kr/download/Satellite/ksp-500D.pdf
http://ksp.kari.re.kr/html/korean/04_sub/sub04_01_01_05.html

KARI Korea Aerospace Research Institute

KSP-500 Series Platform with Payload

	KSP-500E	KSP-500F	KSP-500G	KSP-500H
Payload Type	Multi-spectral Imager	Multi-spectral Imager	Multi-spectral Imager	Multi-spectral Imager
Payload Mass	110 kg	130 kg	160 kg	180 kg
Payload Power	220 W (peak) / 160 W (average)	120 W (peak) / 90 W (average)	180 W (peak) / 130 W (average)	300 W (peak) / 200 W (average)
Applications	Natural resources monitoring, agriculture and forestry mapping, and disaster monitoring	Wide area natural resources monitoring and disaster monitoring	Wide area natural resources monitoring and disaster monitoring	Natural resources monitoring, agriculture and forestry mapping, and disaster monitoring
Communication	160 Mbps Data Downlink	5 Mbps Data Downlink	5 Mbps Data Downlink	320 Mbps Data Downlink
Orbit	528 km			
GSD	30 m	500 m	250 m	30 m
Swath Width	> 120 km	> 500 km	> 500 km	> 150 km
Spectral Bands	8 bands	12 bands	12 bands	12 bands
Designed Life	7 years			
Data Storage Capability	128 Gb	4 Gb	4 Gb	256 Gb
Delivery Schedule	48 months			

Related Platform: KSP-500

http://ksp.kari.re.kr/download/Satellite/ksp-500E.pdf
http://ksp.kari.re.kr/download/Satellite/ksp-500F.pdf
http://ksp.kari.re.kr/download/Satellite/ksp-500G.pdf
http://ksp.kari.re.kr/download/Satellite/ksp-500H.pdf
http://ksp.kari.re.kr/html/korean/04_sub/sub04_01_01_05.html

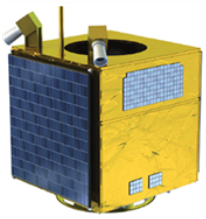
KSP-500 Series Platform with Payload

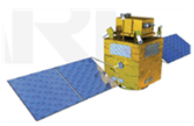
	KSP-500I	KSP-500J
Payload Type	Hyper-spectral Imager	Hyper-spectral Imager
Payload Mass	130 kg	160 kg
Payload Power	240 W (peak) / 175 W (average)	200 W (peak) / 145 W (average)
Applications	Precision natural resources monitoring, disaster monitoring and environmental monitoring	Wide area environmental monitoring
Communication	160 Mbps Data Downlink	5 Mbps Data Downlink
Orbit	528 km	
GSD	3 m	10 km
Swath Width	> 6 km	> 2000 km
Spectral Resolution	10 nm	0,5 nm
Designed Life	7 years	
Data Storage Capability	64 Gb	4 Gb
Delivery Schedule	48 months	

Related Platform: KSP-500

http://ksp.kari.re.kr/download/Satellite/ksp-500I.pdf
http://ksp.kari.re.kr/download/Satellite/ksp-500J.pdf
http://ksp.kari.re.kr/html/korean/04_sub/sub04_01_01_05.html

KSP-501 Series Platform





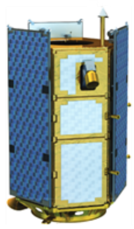
Payload Mass	165 kg
Payload Dimensions	1,2 m x 1,2 m x 0,4 m (H) (internal) / 1,3 m x 1,0 m x up to LV fairing limitation (external)
Payload Power	220 W (average)
Platform Mass	330 kg (without propellant)
Platform Dimensions	1,4 m x 1,4 m x 1,6 m (H) (stowed) / 6,2 m x 1,4 m x 1,6 m (H) (deployed)
Platform Power	1000 W / Batteries: 45 Ah, Li-Ion / Main Bus: 50 V (unregulated)
Applications	Various practical applications
Stabilization Mode	3-axis with reaction wheels and magnetic torquers
Attitude	Pointing Accuracy: 0,020 ° (3σ) / Pointing Stability: 0,007 ° in 10 s (3σ)
Propulsion	30 kg Propellant Capacity / 1 N x 8 Thrusters / 37 L Hydrazine mono-propellant tank
Communication	320 Mbps X-Band Data Downlink / S-Band Telemetry and Telecommand Downlink-Uplink
OBDH	SpaceWire, UART, CAN, MIL-STD-1553B
Thermal	Primarily Passive Type
Orbit	LEO: 500-900 km
Designed Life	7 years
Data Storage Capability	256 Gb
Heritage	KOMPSAT series
Delivery Schedule	38 months

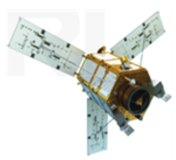
*KSP-501 derived satellites are used for meteorology: KSP-501A/KSP-501B/KSP-501C/KSP-501D

Related Launch Vehicle: Rockot, Minotaur IV, VEGA

http://ksp.kari.re.kr/download/Satellite/KSP-501.pdf
http://ksp.kari.re.kr/html/korean/04_sub/sub04_01_01_06.html

KSP-800 Series Platform





Payload Mass	320 kg
Payload Dimensions	1,4 m x 1,0 m (Diameter x Height) (internal) / 2,0 m (Diameter) x up to LV fairing limitation (external)
Payload Power	240 W (average)
Platform Mass	2,0 m x 2,5 m (Diameter x Height) (stowed) / 6,0 m x 2,5 m (Diameter x Height) (deployed)
Platform Dimensions	410 kg
Platform Power	1000 W / Batteries: 45 Ah, Li-Ion / Main Bus: 50 V (unregulated)
Applications	Earth observation missions requiring high performance and agility
Stabilization Mode	3-axis with reaction wheels and magnetic torquers
Attitude	Pointing Accuracy: 0,015 ° (3σ) / Pointing Stability: 0,004 °/s (3σ) / Pointing Agility: 1,0 °/s
Propulsion	70 kg Propellant Capacity / 1 N x 8 Thrusters / 91 L Hydrazine mono-propellant tank
Communication	640 Mbps X-Band Data Downlink / S-Band Telemetry and Telecommand Downlink-Uplink
OBDH	SpaceWire, UART, CAN, MIL-STD-1553B
Thermal	Primarily Passive Type
Orbit	LEO: 500-700 km
Designed Life	7 years
Data Storage Capability	512 Gb
Heritage	KOMPSAT series
Delivery Schedule	38 months

Related Launch Vehicle: Rockot, Soyuz-1, VEGA

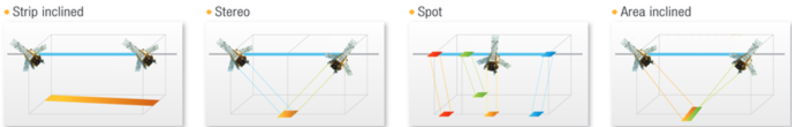
http://ksp.kari.re.kr/download/Satellite/KSP-800.pdf
http://ksp.kari.re.kr/html/korean/04_sub/sub04_01_01_06.html

KOREA AEROSPACE RESEARCH INSTITUTE

KSP-800 Series Platform with Payload

	KSP-800A	KSP-800B	KSP-800C
Payload Type	Electro-Optical Imager	Electro-Optical Imager	Electro-Optical Imager / IR Sensor
Payload Mass	180 kg	190 kg	230 kg
Payload Power	400 W (peak) / 100 W (average)	540 W (peak) / 120 W (average)	760 W (peak) / 240 W (average)
Applications	Wide range of applications both in the civil and security area		
Communication	640 Mbps Data Downlink		
Orbit	528 km		
GSD	PAN: 0,7 m	PAN: 0,7 m / MS: 2,8 m	PAN: 0,7 m / MS: 2,8 m / IR: 7,0 m
Swath Width	> 15 km		
Imaging Modes	Strip Inclined, Stereo, Spot, Area Inclined		
Designed Life	7 years		
Data Storage Capability	512 Gb		
Delivery Schedule	48 months		

Related Platform: KSP-800



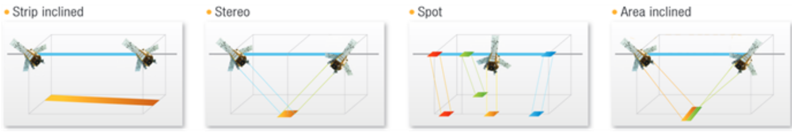
http://ksp.kari.re.kr/download/Satellite/KSP-800A.pdf
http://ksp.kari.re.kr/download/Satellite/KSP-800B.pdf
http://ksp.kari.re.kr/download/Satellite/KSP-800C.pdf
http://ksp.kari.re.kr/html/korean/04_sub/sub04_01_01_06.html

KOREA AEROSPACE RESEARCH INSTITUTE

KSP-800 Series Platform with Payload

	KSP-800A	KSP-800B	KSP-800C
Payload Type	Electro-Optical Imager	Electro-Optical Imager	Electro-Optical Imager / IR Sensor
Payload Mass	180 kg	190 kg	230 kg
Payload Power	400 W (peak) / 100 W (average)	540 W (peak) / 120 W (average)	760 W (peak) / 240 W (average)
Applications	Wide range of applications both in the civil and security area		
Communication	640 Mbps Data Downlink		
Orbit	528 km		
GSD	PAN: 0,7 m	PAN: 0,7 m / MS: 2,8 m	PAN: 0,7 m / MS: 2,8 m / IR: 7,0 m
Swath Width	> 15 km		
Imaging Modes	Strip Inclined, Stereo, Spot, Area Inclined		
Designed Life	7 years		
Data Storage Capability	512 Gb		
Delivery Schedule	48 months		

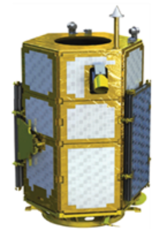
Related Platform: KSP-800

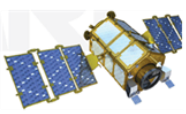


http://ksp.kari.re.kr/download/Satellite/KSP-800A.pdf
http://ksp.kari.re.kr/download/Satellite/KSP-800B.pdf
http://ksp.kari.re.kr/download/Satellite/KSP-800C.pdf
http://ksp.kari.re.kr/html/korean/04_sub/sub04_01_01_06.html

KOREA AEROSPACE RESEARCH INSTITUTE

KSP-801 Series Platform





Payload Mass	320 kg
Payload Dimensions	1,4 m x 1,0 m (Diameter x Height) (internal) / 2,0 m (Diameter) x up to LV fairing limitation (external)
Payload Power	240 W (average)
Platform Mass	410 kg
Platform Dimensions	2,0 m x 2,5 m (Diameter x Height) (stowed) / 7,0 m x 2,5 m (Diameter x Height) (deployed)
Platform Power	1000 W / Batteries: 45 Ah, Li-Ion / Main Bus: 50 V (unregulated)
Applications	Various practical applications
Stabilization Mode	3-axis with reaction wheels and magnetic torquers
Attitude	Pointing Accuracy: 0,023 ° (3σ) / Pointing Stability: 0,005 °/s (3σ)
Propulsion	70 kg Propellant Capacity / 1 N x 8 Thrusters / 91 L Hydrazine mono-propellant tank
Communication	640 Mbps Data Downlink / S-Band Telemetry and Telecommand Downlink-Uplink
OBDH	SpaceWire, UART, CAN, MIL-STD-1553B
Thermal	Primarily Passive Type
Orbit	LEO: 500-700 km
Designed Life	7 years
Data Storage Capability	512 Gb
Heritage	KOMPSAT series
Delivery Schedule	38 months

Related Launch Vehicle: Rockot, Soyuz-1, VEGA

http://ksp.kari.re.kr/download/Satellite/KSP-801.pdf
http://ksp.kari.re.kr/html/korean/04_sub/sub04_01_01_08.html

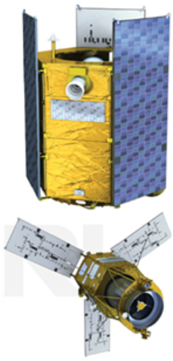
KSP-801 Series Platform with Payload

	KSP-801A	KSP-801B	KSP-801C
Payload Type	Electro-Optical Imager	Electro-Optical Imager	Electro-Optical Imager / IR Sensor
Payload Mass	180 kg	190 kg	230 kg
Payload Power	400 W (peak) / 100 W (average)	560 W (peak) / 120 W (average)	760 W (peak) / 240 W (average)
Applications	Wide range of applications both in the civil and security area		
Communication	640 Mbps Data Downlink		
Orbit	528 km		
GSD	PAN: 0,7 m	PAN: 0,7 m / MS: 2,8 m	PAN: 0,7 m / MS: 2,8 m / IR: 7,0 m
Swath Width	> 15 km		
Designed Life	7 years		
Data Storage Capability	512 Gb		
Delivery Schedule	48 months		

Related Platform: KSP-801

http://ksp.kari.re.kr/download/Satellite/KSP-801A.pdf
http://ksp.kari.re.kr/download/Satellite/KSP-801B.pdf
http://ksp.kari.re.kr/download/Satellite/KSP-801C.pdf
http://ksp.kari.re.kr/html/korean/04_sub/sub04_01_01_08.html

KSP-1000 Series Platform



Payload Mass	440 kg
Payload Dimensions	1,4 m x 1,0 m (Diameter x Height) (internal) / 1,7 m (Diameter) x up to LV fairing limitation (external)
Payload Power	300 W (average)
Platform Mass	590 kg
Platform Dimensions	2,0 m x 2,6 m (Diameter x Height) (stowed) / 6,0 m x 2,6 m (Diameter x Height) (deployed)
Platform Power	1400 W / Batteries: 52 Ah, Li-Ion / Main Bus: 50 V (unregulated)
Applications	Earth observation missions requiring high performance and agility
Stabilization Mode	3-axis with reaction wheels and magnetic torquers
Attitude	Pointing Accuracy: 0,015 ° (3σ) / Pointing Stability: 0,004 °/s (3σ) / Pointing Agility: 1,0 °/s
Propulsion	70 kg Propellant Capacity / 4,45 N x 8 Thrusters / 91 L Hydrazine mono-propellant tank
Communication	640 Mbps Data Downlink / S-Band Telemetry and Telecommand Downlink-Uplink
OBDH	SpaceWire, UART, CAN, MIL-STD-1553B
Thermal	Primarily Passive Type
Orbit	LEO: 500-700 km
Designed Life	7 years
Data Storage Capability	512 Gb
Heritage	KOMPSAT series
Delivery Schedule	42 months

Related Launch Vehicle: Rockot, Soyuz-1, VEGA

http://ksp.kari.re.kr/download/Satellite/KSP-1000.pdf
http://ksp.kari.re.kr/html/korean/04_sub/sub04_01_01_09.html

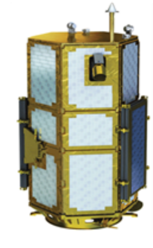
KSP-1000 Series Platform with Payload

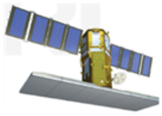
	KSP-1000A	KSP-1000B	KSP-1000C	KSP-1000D
Payload Type	Electro-Optical Imager	Electro-Optical Imager	Electro-Optical Imager / IR Sensor	L-Band SAR
Payload Mass	230 kg	240 kg	270 kg	280 kg
Payload Power	500 W (peak) / 120 W (average)	700 W (peak) / 150 W (average)	950 W (peak) / 300 W (average)	1000 W (peak) / 160 W (average)
Applications	Wide range of applications both in the civil and security area	Wide range of location based services	Security, disaster management and location based services	High accyracy mapping, security and surveillance and disaster management
Communication	640 Mbps Data Downlink			
Orbit	528 km	528 km	528 km	550 km
GSD	PAN: 0,5 m	PAN: 0,5 m / MS: 2 m	PAN: 0,5 m / MS: 2 m / IR: 5 m	High: 3 m / Medium: 10 m / Low: 20 m
Incidence Angle				20-55 °
Swath Width	> 15 km	> 15 km	> 15 km	Spot: 20 km / Strip: 30 km / Scan: 100 km
Designed Life	7 years			
Data Storage Capability	512 Gb			
Delivery Schedule	54 Months			

Related Platform: KSP-1000

http://ksp.kari.re.kr/download/Satellite/KSP-1000A.pdf
http://ksp.kari.re.kr/download/Satellite/KSP-1000B.pdf
http://ksp.kari.re.kr/download/Satellite/KSP-1000C.pdf
http://ksp.kari.re.kr/download/Satellite/KSP-1000D.pdf
http://ksp.kari.re.kr/html/korean/04_sub/sub04_01_01_09.html

KSP-1001 Series Platform





Payload Mass	410 kg
Payload Dimensions	2,0 m (Diameter) x up to LV fairing limitation (external)
Payload Power	510 W (average)
Platform Mass	620 kg
Platform Dimensions	2,0 m x 2,5 m (Diameter x Height) (stowed) / 8,0 m x 2,5 m (Diameter x Height) (deployed)
Platform Power	1500 W / Batteries: 104 Ah, Li-Ion / Main Bus: 50 V (unregulated)
Applications	Various practical applications
Stabilization Mode	3-axis with reaction wheels and magnetic torquers
Attitude	Pointing Accuracy: 0,020 ° (3σ) / Pointing Stability: 0,007 ° in 10 s (3σ)
Propulsion	70 kg Propellant Capacity / 4,45 N x 8 Thrusters / 91 L Hydrazine mono-propellant tank
Communication	640 Mbps Data Downlink / S-Band Telemetry and Telecommand Downlink-Uplink
OBDH	SpaceWire, UART, CAN, MIL-STD-1553B
Thermal	Primarily Passive Type
Orbit	LEO: 500-700 km
Designed Life	7 years
Data Storage Capability	512 Gb
Heritage	KOMPSAT series
Delivery Schedule	42 months

Related Launch Vehicle: Rockot, Soyuz-1, VEGA

http://ksp.kari.re.kr/download/Satellite/KSP-1001.pdf
http://ksp.kari.re.kr/html/korean/04_sub/sub04_01_01_10.html

KSP-1001A Platform with Payload

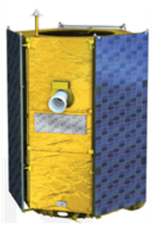
Payload Type	S-Band SAR
Payload Mass	200 kg
Payload Power	6000 W (peak) / 510 W (average)
Platform Mass	620 kg
Platform Dimensions	3,5 m x 4,0 m (Diameter x Height) (stowed) / 8,0 m x 4,0 m (Diameter x Height) (deployed)
Platform Power	1500 W / Batteries: 104 Ah, Li-Ion / Main Bus: 50 V (unregulated)
Applications	Various practical applications
Stabilization Mode	3-axis with reaction wheels and magnetic torquers
Attitude	Pointing Accuracy: 0,025 ° (3σ) / Pointing Stability: 0,007 ° in 10 s (3σ)
Propulsion	70 kg Propellant Capacity / 4,45 N x 8 Thrusters / 91 L Hydrazine mono-propellant tank
Communication	640 Mbps Data Downlink / S-Band Telemetry and Telecommand Downlink-Uplink
OBDH	SpaceWire, UART, CAN, MIL-STD-1553B
Thermal	Primarily Passive Type
Orbit	550 km
GSD	Fine: 5 m / Standard: 25 m
Incidence Angle	20-55 °
Swath Width	Strip: 30 km / Scan: 100 km
Designed Life	7 years
Data Storage Capability	512 Gb
Heritage	KOMPSAT series
Delivery Schedule	54 months

Related Platform: KSP-1001

Related Launch Vehicle: Soyuz-1, Falcon-9

http://ksp.kari.re.kr/download/Satellite/KSP-1001A.pdf
http://ksp.kari.re.kr/html/korean/04_sub/sub04_01_01_10.html

KSP-1500 Series Platform

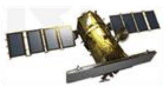


Payload Mass	750 kg
Payload Dimensions	1,8 m x 1,0 m (Diameter x Height) (internal) / 2,0 m (Diameter) x up to LV fairing limitation (external)
Payload Power	350 W (average)
Platform Mass	680 kg
Platform Dimensions	2,5 m x 2,5 m (Diameter x Height) (stowed) / 7,0 m x 2,5 m (Diameter x Height) (deployed)
Platform Power	1500 W / Batteries: 77 Ah, Li-Ion / Main Bus: 50 V (unregulated)
Applications	Earth Observation missions requiring a very high performance
Stabilization Mode	3-axis with reaction wheels and magnetic torquers
Attitude	Pointing Accuracy: 0,015 ° (3σ) / Pointing Stability: 0,004 °/s (3σ) / Pointing Agility: 1,0 °/s
Propulsion	70 kg Propellant Capacity / 4,45 N x 8 Thrusters / 91 L Hydrazine mono-propellant tank
Communication	640 Mbps Data Downlink / S-Band Telemetry and Telecommand Downlink-Uplink
OBDH	SpaceWire, UART, CAN, MIL-STD-1553B
Thermal	Primarily Passive Type
Orbit	LEO: 500-700 km
Designed Life	7 years
Data Storage Capability	512 Gb
Heritage	KOMPSAT series
Delivery Schedule	42 months

Related Launch Vehicle: Soyuz-1, PSLV, Falcon-9

http://ksp.kari.re.kr/download/Satellite/KSP-1500.pdf
http://ksp.kari.re.kr/html/korean/04_sub/sub04_01_01_11.html

KSP-1501 Series Platform



Payload Mass	720 kg
Payload Dimensions	2,5 m (Diameter) x up to LV fairing limitation (external)
Payload Power	520 W
Platform Mass	710 kg
Platform Dimensions	2,5 m x 3,0 m (Diameter x Height) (stowed) / 9,0 m x 3,0 m (Diameter x Height) (deployed)
Platform Power	1600 W / Batteries: 104 Ah, Li-Ion / Main Bus: 50 V (unregulated)
Applications	SAR missions requiring a high performance
Stabilization Mode	3-axis with reaction wheels and magnetic torquers
Attitude	Pointing Accuracy: 0,020 ° (3σ) / Pointing Stability: 0,007 ° in 10 s (3σ)
Propulsion	70 kg Propellant Capacity / 4,45 N x 8 Thrusters / 91 L Hydrazine mono-propellant tank
Communication	640 Mbps Data Downlink / S-Band Telemetry and Telecommand Downlink-Uplink
OBDH	SpaceWire, UART, CAN, MIL-STD-1553B
Thermal	Primarily Passive Type
Orbit	LEO: 500-700 km
Designed Life	7 years
Data Storage Capability	512 Gb
Heritage	KOMPSAT series
Delivery Schedule	42 months

Related Launch Vehicle: Soyuz-1, PSLV, Falcon-9

http://ksp.kari.re.kr/download/Satellite/KSP-1501.pdf
http://ksp.kari.re.kr/html/korean/04_sub/sub04_01_01_12.html

KSP-1501A Platform with Payload

Payload Type	X-Band SAR
Payload Mass	520 kg
Payload Power	6500 W (peak) / 520 W (average)
Platform Mass	710 kg
Platform Dimensions	2,5 m x 4,0 m (Diameter x Height) (stowed) / 9,0 m x 4,0 m (Diameter x Height) (deployed)
Platform Power	1600 W / Batteries: 104 Ah, Li-Ion / Main Bus: 50 V (unregulated)
Applications	Defense and security, topographic mapping, maritime detection, precision natural resources monitoring, disaster monitoring and location based services
Stabilization Mode	3-axis with reaction wheels and magnetic torquers
Attitude	Pointing Accuracy: 0,025 ° (3σ) / Pointing Stability: 0,007 ° in 10 s (3σ)
Propulsion	70 kg Propellant Capacity / 4,45 N x 8 Thrusters / 91 L Hydrazine mono-propellant tank
Communication	640 Mbps Data Downlink / S-Band Telemetry and Telecommand Downlink-Uplink
OBDH	SpaceWire, UART, CAN, MIL-STD-1553B
Thermal	Primarily Passive Type
Orbit	550 km
GSD	Spot: 1 m / Strip: 3 m / Scan: 20 m
Incidence Angle	20-55 °
Swath Width	Spot: 5 km / Strip: 30 km / Scan: 100 km
Designed Life	7 years
Data Storage Capability	512 Gb
Heritage	KOMPSAT series
Delivery Schedule	54 months

Related Launch Vehicle: Soyuz-1, PSLV, Falcon-9

http://ksp.kari.re.kr/download/Satellite/KSP-1501A.pdf
http://ksp.kari.re.kr/html/korean/04_sub/sub04_01_01_12.html

KSP-2000 Series Platform

Payload Mass	1030 kg
Payload Dimensions	1,8 m x 1,0 m (Diameter x Height) (internal) / 2,0 m (Diameter) x up to LV fairing limitation (external)
Payload Power	350 W (average)
Platform Mass	900 kg
Platform Dimensions	2,5 m x 3,0 m (Diameter x Height) (stowed) / 8,0 m x 3,0 m (Diameter x Height) (deployed)
Platform Power	1700 W / Batteries: 90 Ah, Li-Ion / Main Bus: 50 V (unregulated)
Applications	Multi-purpose missions requiring a very high performance and agility
Stabilization Mode	3-axis with reaction wheels/control momentum gyroscopes and magnetic torquers
Attitude	Pointing Accuracy: 0,015 ° (3σ) / Pointing Stability: 0,004 °/s (3σ) / Pointing Agility: 1,0 °/s
Propulsion	70 kg Propellant Capacity / 4,45 N x 8 Thrusters / 91 L Hydrazine mono-propellant tank
Communication	640 Mbps Data Downlink / S-Band Telemetry and Telecommand Downlink-Uplink
OBDH	SpaceWire, UART, CAN, MIL-STD-1553B
Thermal	Primarily Passive Type
Orbit	LEO: 500-700 km
Designed Life	7 years
Data Storage Capability	512 Gb
Heritage	KOMPSAT series
Delivery Schedule	42 months

Related Launch Vehicle: Falcon-9, Soyus-Fregat

http://ksp.kari.re.kr/download/Satellite/KSP-2000.pdf
http://ksp.kari.re.kr/html/korean/04_sub/sub04_01_01_13.html

KARI Korea Aerospace Research Institute

KSP-2001 Series Platform

Payload Mass	1000 kg
Payload Dimensions	2,5 m (Diameter) x up to LV fairing limitation (external)
Payload Power	950 W (average)
Platform Mass	930 kg
Platform Dimensions	2,5 m x 3,5 m (Diameter x Height) (stowed) / 10,0 m x 3,5 m (Diameter x Height) (deployed)
Platform Power	2000 W / Batteries: 135 Ah, Li-Ion / Main Bus: 50 V (unregulated)
Applications	Multi-purpose missions requiring a high performance
Stabilization Mode	3-axis with reaction wheels and magnetic torquers
Attitude	Pointing Accuracy: 0,020 ° (3σ) / Pointing Stability: 0,007 ° in 10 s (3σ)
Propulsion	70 kg Propellant Capacity / 4,45 N x 8 Thrusters / 91 L Hydrazine mono-propellant tank
Communication	640 Mbps Data Downlink / S-Band Telemetry and Telecommand Downlink-Uplink
OBDH	SpaceWire, UART, CAN, MIL-STD-1553B
Thermal	Primarily Passive Type
Orbit	LEO: 500-700 km
Designed Life	7 years
Data Storage Capability	512 Gb
Heritage	KOMPSAT series
Delivery Schedule	42 months

Related Launch Vehicle: Falcon-9, Soyus-Fregat

http://ksp.kari.re.kr/download/Satellite/KSP-2001.pdf
http://ksp.kari.re.kr/html/korean/04_sub/sub04_01_01_14.html

LOCKHEED MARTIN

They were selected by GeoEye, Inc., to build the company's next-generation, high-resolution, Earth-imaging satellite and associated command and control system, known as GeoEye-2.

They offer:

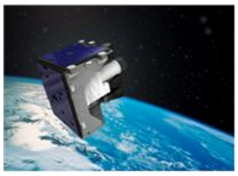
- **Complete satellites**
- **Platforms**
- **Launch services** on Atlas launch vehicle

They supplied the platform for GeoEye-2 mission (Exilis payload)
They have 50 years of experience in remote sensing and have launched nearly 800 spacecraft.
They offer launch services on Atlas launch vehicle.

http://www.lockheedmartin.com/us/products/geoeye2.html
http://www.lockheedmartin.com/us/what-we-do/space/earth-observation-exploration.html
http://www.lockheedmartin.com/content/dam/lockheed/data/space/documents/a2100/Commercial%20Remote%20Sensing%20FINAL%20May%202014.pdf

MDA™

MDA is a global communications and information company providing operational solutions to commercial and government organizations worldwide.



They offer:

- **Complete satellites** for radar missions and other missions (based on earth observation solutions)

http://www.mdacorporation.com/corporate/index.cfm
http://www.mdacorporation.com/corporate/surveillance_intelligence/space_missions.cfm

NORTHROP GRUMMAN

Decades of experience as both an instrument developer and a systems prime contractor integrating highly reliable sensors.

They offer:

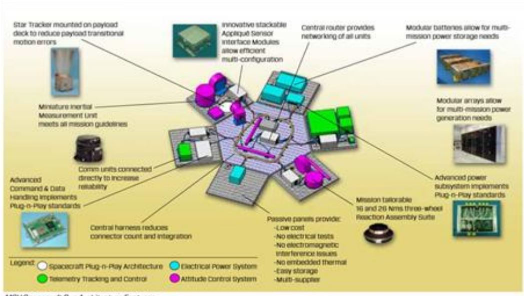
- -**Complete satellites**
- -**Optical** and **Radar** payloads
- -**Platforms**

Flight experience: CERES flight-qualified instruments, NPOESS (meteorological instruments), Aqua & Aura (satellites), DSP-14 to DSP-23 (military satellites with IR sensors), Hyperion hyperspectral imager (1st of its kind, 220 bands), Trinidad (SAR planned satellite)

http://www.northropgrumman.com/Capabilities/EagleSpacecraft/Documents/pageDocs/Modular_Space_Vehicle_Bus_Datasheet.pdf
http://www.northropgrumman.com/Capabilities/SensorsandInstruments/Pages/default.aspx

NORTHROP GRUMMAN

Modular Space Vehicle Bus



MSV Spacecraft Bus Architecture Features

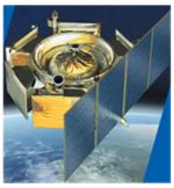
Applications	Multimission applications
Payload Description	Modular RF and electro-optical payloads for communciations, tactical persistente intelligence, surveillance and reconnaissance, tactical electronic support and space situational awareness
Platform Description	Multimission bus architecture that employs a Modular Open System Approach, using Plug-n-Play technology
Delivery Schedule	30 months
Platforms Based on this Architecture	Eagle-1M

Related Launch Vehicle: None

http://www.northropgrumman.com/Capabilities/EagleSpacecraft/Documents/pageDocs/Modular_Space_Vehicle_Bus_Datasheet.pdf

NORTHROP GRUMMAN

EAGLE-S Spacecraft



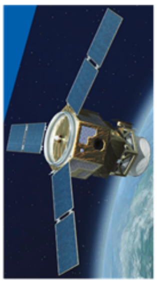
Payload Mass	180 kg per available ESPA (EELV Secondary Payload Adapter) port, maximum 6800 kg mounted to upper interface
Payload Power	795 W or greater
Payload Interface Architecture	SpaceWire (100 Mbps) / MIL-STD-1553B (330 kbps) / RS-422 (10 Mbps)
Attitude	Pointing Knowledge: 22-60 arcsec (3σ) [Higher performance available using payload data] / Pointing Control: 1550 arcsec (3σ) [Higher performance using reaction wheels]
Propulsion	Monoprop, 800 m/s or greater
Designed Life	3 years (selective redundancy) / 7 years (full redundancy option)
Data Storage Capability	Up to 384 Gb (SDRAM) or 1526 Gb (flash)
Flight Experience	LCROSS
Delivery Schedule	20 months from authorization

Related Launch Vehicles: Antares, Falcon 9, Falcon Heavy, EELV

http://www.northropgrumman.com/Capabilities/EagleSpacecraft/Documents/pageDocs/Eagle_S_datasheet.pdf
http://www.northropgrumman.com/Capabilities/EagleSpacecraft/Documents/pageDocs/Eagle_brochure.pdf

NORTHROP GRUMMAN

EAGLE-1M Spacecraft



Payload Mass	> 175 kg
Payload Power	500 W (average) / 1200 W (peak at short duty cycle)
Payload Interface Architecture	SpaceWire (additional formats can be implemented)
Attitude	Pointing Knowledge: 90 arcsec (3σ) (12 arcsec optional) [Higher performance available using payload data] / Pointing Control: 0,05 ° (3σ) / Agility Rate: 2°/s / Agility Acceleration: > 0,03°/s^2 / Orbit Position Knowledge via GPS: ± 90 m (3σ)
Propulsion	200 m/s modular add-on option
Communication	Wideband communications
Designed Life	3 years
Flight Experience	ROCSAT-1, TOMS-EP, KOMPSAT-1
Delivery Schedule	20 months from authorization

Related Launch Vehicles: Minotaur I, Taurus 3210, Minotaur IV, Delta II

http://www.northropgrumman.com/Capabilities/EagleSpacecraft/Documents/pageDocs/Eagle-1_datasheet.pdf
http://www.northropgrumman.com/Capabilities/EagleSpacecraft/Documents/pageDocs/Eagle_brochure.pdf

NORTHROP GRUMMAN

EAGLE-2 Spacecraft

Payload Mass	550 – 1000 kg or greater (depends on launch vehicle and payload CG)
Payload Power	795 W or greater
Payload Interface Architecture	SpaceWire (100 Mbps) / MIL-STD-1553B (330 kbps) / RS-422 (10 Mbps)
Attitude	Pointing Knowledge: 22 arcsec (3σ) [Higher performance available using payload data] / Pointing Control: 100 arcsec (3σ)
Propulsion	Monoprop, 224 m/s or greater
Designed Life	7years
Data Storage Capability	Up to 384 Gb (SDRAM) or 1526 Gb (flash)
Flight Experience	ROCSAT-1, TOMS-EP, KOMPSAT-1
Delivery Schedule	28 months from authorization

Related Launch Vehicles: Taurus 3210, Minotaur IV, Delta II, Antares, Falcon 9, Falcon Heavy, EELV

http://www.northropgrumman.com/Capabilities/EagleSpacecraft/Documents/pageDocs/Eagle-2_datasheet.pdf
http://www.northropgrumman.com/Capabilities/EagleSpacecraft/Documents/pageDocs/Eagle_brochure.pdf

NORTHROP GRUMMAN

EAGLE-3 Spacecraft for LEO

Payload Mass	1175 kg or greater
Payload Power	4000 W or greater
Payload Interface Architecture	MIL-STD-1553B (1 Mbps) / IEEE-1394 (100 Mbps)
Attitude	Pointing Knowledge: 22 arcsec (3σ) [Higher performance available using payload data] / Pointing Control: 50 arcsec (3σ) / Agility Rate: optional / Agility Aceleration: optional
Propulsion	Monoprop, 260 m/s or greater
Communications	Wideband communications (optional)
Designed Life	Up to 7 years
Flight Experience	EOS Aqua, EOS Aura

Related Launch Vehicles: Falcon 9, Falcon Heavy, EELV

http://www.northropgrumman.com/Capabilities/EagleSpacecraft/Documents/pageDocs/Eagle-3_datasheet.pdf
http://www.northropgrumman.com/Capabilities/EagleSpacecraft/Documents/pageDocs/Eagle_brochure.pdf

EOS Aqua & Aura Satellites (based on Eagle-3 platform)

NORTHROP GRUMMAN

	AQUA	AURA
Mass	3022 kg (1940 kg S/C + 1082 kg instruments)	2967 kg (1767 kg S/C + 1200 kg instruments)
Dimensions	2,68 m x 2,47 m x 6,49 m (stowed) 4,78 m x 17,03 m x 6,67 m (deployed)	2,68 m x 2,34 m x 6,85 m (stowed) 4,7 m x 17,03 m x 6,85 m (deployed)
Power	4740 W (EOL)	4440 W (EOL)
Orbit	705 km, sun-synchronous	705 km, sun-synchronous
Communications	S-Band telemetry	
Applications	Meteorology	
Instruments	Atmospheric Infrared Sounder, Advanced Microwave Scanning Radiometer, Advanced Microwave Sounding Unit, Clouds and the Earth's Radiant Energy System, Humidity Sounder for Brazil and Moderate Resolution Imaging Spectroradiometer	Microwave Limb Sounder, Tropospheric Emission Spectrometer, High Resolution Dynamics Limb Sounder, Ozone Monitoring Instrument

http://www.northropgrumman.com/Capabilities/EOSAqua/Pages/default.aspx
http://www.northropgrumman.com/Capabilities/EOSAqua/Documents/pageDocs/EOS_Aqua_datasheet.pdf
http://www.northropgrumman.com/Capabilities/EOSAqua/Documents/pageDocs/Aqua_Afternoon_FactSheet.pdf
http://www.northropgrumman.com/Capabilities/EOSAura/Pages/default.aspx
http://www.northropgrumman.com/Capabilities/EOSAura/Documents/pageDocs/EOS_Aura_datasheet.pdf
http://www.northropgrumman.com/Capabilities/EOSAura/Documents/pageDocs/Aura_Tech_Specs_FS.pdf

OHB

OHB have been on the market for 35 years particularly in their core business comprising low-orbiting and geostationary satellites.

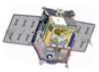
They offer:

- **Complete satellites**
- **Optical** and **Radar** payloads
- **Platforms**

Flight experience: SAR-Lupe reconnaissance satellites, SARah reconnaissance system, Galileo navigation satellites, the MTG meteorological satellites, the EnMAP environment satellite, the TET-1 technology testing vehicle and the HispaSat, ELECTRA and EDRS-C telecommunications satellites, MTG Infrared Sounder, MTG Flexible Combined Imager, EnMAP Hyperspectral instrument, etc.

https://www.ohb-system.de

OHB



TET – Small Satellite Series Platforms

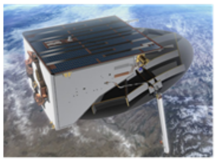
	TET-X	TET-XL
Payload Mass	50 kg	80 kg
Payload Volume	90 dm^3	170 dm^3
Payload Power	Continuos: 80 W (or more, depending on selected orbit and heat rejection possibilities) / Peak: 160 W for 20 min.	Continuos: 150 W (or more, depending on selected orbit and heat rejection possibilities) / Peak: 460 W for 25 min.
Platform Mass	120 kg	200 kg
Platform Dimensions	580 mm x 880 mm x 670 mm (W x H x D)	800 mm x 845 mm x 800 mm (W x H x D)
Platform Volume	320 dm^3	520 dm^3
Stabilization mode	3-axes stabilized (4 reaction wheels)	
Redundancy	Service Module fully redundant	
Attitude	Pointing accuracy: typ. 2 arcmin / Pointing knowledge: typ. 10 arcsec / Positioning Knowledge: < 10 m	
Typical ΔV		60 m/s (for 250 kg S/C mass) 83 m/s (for 150 kg S/C mass)
Communication	S-band, TC: 4-256 kbps, TM: 2,2-6 Mbps	S-band, TC: 4-256 kbps, TM: 6 Mbps
Orbit	450-850 km altitude, 53°-sun synchronous inclination	
Designed Life	3-5 years	Up to 7 years
Other Characteristics	3 solar panels (1 fixed plus 2 deployable)	
Optional Characteristics	5 solar panels, 100 Mbps X-Band payload data downlink, micro propulsion system, encryption/decryption, authentication	5 solar panels, 400 Mbps X-Band payload data downlink, 1,2 Gbps Ka-Band payload data downlink, encryption/decryption, authentication
Flight Experience	TET-1 @ 510 km	

Related Launch Vehicle: None

https://www.ohb-system.de
https://www.ohb-system.de/tl_files/system/images/mediathek/downloads/pdf/OHB_Messe_TET_2014_web.pdf

SAR-Lupe Satellite

OHB-System AG developed the overall system as the principal contractor for the German government for the SAR-Lupe satellite-based reconnaissance system.



Dimensions	4 m x 3 m x 2 m
Mass	720 kg
Average Power Consumption	250 W
Orbit	500 km
Life	10 years
Reliability	Better than 97% per year
Communications	Encrypted X-Band for data transmission, S-Band transmission for encrypted command and telemetry via ground station and intersatellite link
Attitude Control	By reaction wheels and magnetic torquers
Orbit Control	Liquid gas thrusters
Spatial Resolution	< 1 m
Number of Satellites	5

Related Launch Vehicle: None

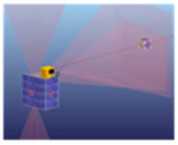
https://www.ohb-system.de
https://www.ohb-system.de/tl_files/system/images/mediathek/downloads/pdf/120830_OHB_10604_Messe_SAR-Lupe_2012.pdf

OHB Sweden is specialized in developing micro- and mini-satellites in the range from a few 10th of kilograms up to about 500 kg

They offer:

-**Complete satellites**
-**Platforms**

PRISMA PLATFORM*:



Payload Mass	50-100 kg
Platform Mass	Around 100 kg (scalable depending on the mission)
Applications	LEO missions for Earth observation or Science
Features	Very flexible and agile atitude and orbit control system
Flight Experience	Prisma satellites (Mango & Tango)

*Prisma platform is not the same Prisma payload and platform that SELEX ES offers

Related Launch Vehicle: None

http://www.ohb-sweden.se/prisma
http://www.ohb-sweden.se/node/13
http://www.sebroschyr.se/ohb/WebView/

Astrid Platforms

Astrid-1 Platform:

Payload Mass	4,36 kg
Payload Power	11,88 W
Platform Mass	27 kg
Platform Dimensions	290 mm x 450 mm x 450 mm (H x W x D)
Features	Spin Stabilized, Sun Pointing, $1,4 million price
Flight Experience	Astrid-1

Related Launch Vehicle: Piggyback on Kosmos-3M

Astrid-2 Platform:

Payload Mass	9 kg
Payload Power	16 W (continuosly)
Platform Mass	< 30 kg
Platform Dimensions	1700 mm x 1100 mm x 300 (deployed)
Features	Spin Stabilized, Sun Pointing, 128 kbps Downlink Data Rate
Flight Experience	Astrid-2

Related Launch Vehicle: Piggyback on Kosmos-3M

http://www.ohb-sweden.se/node/29
http://www.ohb-sweden.se/node/13

Orbital is an industry focused on the development of spacecraft designed to provide commercial Earth imaging services.

Merged with ATK in February 2015. This information is not more available online

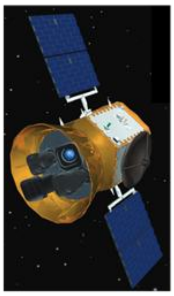
They offer:

- **Complete satellites**
- **Platforms**
- **Launch services**

Flight experience: GeoEye-1, OrbView-4, OrbView-3, OrbView-2/SeaStar, OrbView-1/MicroLab-1, Earlybird-1

http://www.orbital.com/SatelliteSpaceSystems/CommunicationsImagingSatellites/ImagingSatellites/

LEOStar-2

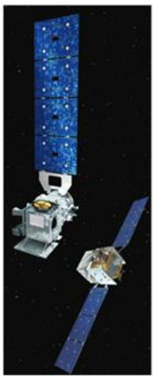


Payload Mass	210 kg (standard), up to 500 kg (optional)
Payload Volume	Up to 1,388 m^3 in Pegasus XL
Payload Power	118 W orbit average (standard), up to 2 kW (optional)
Payload Interface Architecture	RS-422/RS-485, LVDS, MIL-STD-1553
Platform Mass	150 kg to 500 kg (with propellant)
Stabilization mode	3-axis
Attitude	ADCS Approach: S-band at 2 Mbps (optional X-band at 15 Mbps) Pointing Accuracy: < 15 arcsec/axis (3σ) / Pointing Knowledge: < 6 arcsec/axis (3σ) / Pointing Stability: < 1 arcsec/s / Agility: Slew rate up to 1 °/s per axis (standard) or > 3 °/s (optional)
Propulsion	Blowdown monopropellant hydrazine / up to 140 kg propellant (optional)
Communication	Payload data downlink: 2 Mbps S-Band (standard) or up to 150 Mbps X-band (optional) / Command uplink: 2 kbps S-band (standard) or up to 128 kbps (optional)
Orbit	LEO: 450-1000 km altitude, 5°-110° inclination (adaptable to HEO, GEO and deep space)
Designed Life	Up to 5 years
Onboard Data Storage Capability	Scalable to 1600 Gbit in data recorder and 32 Gbit in flight computer
Geolocation	< 12 m @ 90% Circular Error, post processing (optional)
Operations	Simultaneous data acquisition by payload(s) and data transmission capability
Flight Experience	Four satellites with this platform on orbit, and three more in production
Delivery Schedule	30-36 months after receipt of order

Related Launch Vehicle: Pegasus XL. Also compatible with Pegasus, Minotaur and Delta II and Falcon

http://www.orbital.com/SatelliteSpaceSystems/Publications/LEOStar-2_factsheet.pdf
http://www.orbital.com/SatelliteSpaceSystems/CommunicationsImagingSatellites/ImagingSatellites/

LEOStar-3



Payload Mass	Up to 4000 kg
Payload Dimensions	1,8 m x 1,8 m x 1,4m (Nominal Instrument Volume) according to the payload flexure interface
Payload Power	775 W
Platform Mass	1169 kg (plus 353 kg of propellent)
Stabilization mode	3-axis
Attitude	Pointing control: 120 arcsec (1σ) / Pointing Knowledge: < 5 arcsec / Timing accuracy: 40 µs / Orbit knowledge: 33 m (1σ) / Max Maneuver Rate: 0,125°/s or up to 3°/s (optional)
Propulsion	Blowdown monopropellant hydrazine, up to 353 kg
Communication	Payload data downlink: 2 Mbps S-Band (standard) or up to 740 Mbps X-band (optional) or 320 Mbps Ka-Band / Command uplink: S-band (standard) / Space-to-Space Mission Data: Laser LCT (optional)
Orbit	LEO, interplanetary
Designed Life	7-10 years
Onboard Data Storage Capability	160 Gb (solid state mission data storage available to 3100 Gb as optional)
Total Radiation Dose	25 krad
Flight Experience	GeoEye-1, Landsat 8
Delivery Schedule	21-36 months after authorization to Proceed (ATP). 36-48 months from ATP to launch.

Related Launch Vehicles: Antares. Also compatible with Minotaur IV, Antares, Delta II, Delta IV, Falcon 9, Atlas V

http://www.orbital.com/SatelliteSpaceSystems/Publications/LEOStar-3_factsheet.pdf
http://www.orbital.com/SatelliteSpaceSystems/CommunicationsImagingSatellites/ImagingSatellites/
http://www.orbitalatk.com/space-systems/commercial-satellites/imaging-satellites/docs/LEOStar-2_Fact_Sheet.pdf
http://www.orbitalatk.com/space-systems/commercial-satellites/imaging-satellites/docs/LEOStar-3_Fact_Sheet.pdf

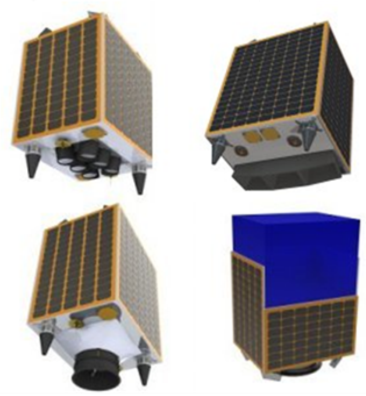
They have been delivering small satellite missions for over 25 years. SSTL is an independent British company within the Airbus Defence & Space Group

They offer:

- **Complete satellites** for any payload under 1000 kg
- **Optical** and **Radar** payloads
- **Platforms**
- They have relationships with major launch providers.

http://www.sstl.co.uk/Products/EO-Payloads

SSTL-X50 Series Platform

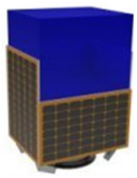


A single system architecture and technology designed to meet all mission applications and requirements across the entire range. Baselined from heritage designs, core platform services such as power, structure, processing, communications and high-precision attitude control are scaled to meet any mission on **a 50kg platform** that includes variants **EarthMapper**, **TrueColour**, **Precision** and **Payload-Ready Platform**.

Related Launch Vehicle: None (However SSTL offers launch contract negotiation)

http://www.sstl.co.uk/Products/EO---Science-Platforms

SSTL-X50 Series Platform



Payload Mass	Up to 45 kg
Payload Volume	530 mm x 430 mm x 400 mm (W x D x H)
Payload Power	35 W (average) / 85 W (peak) [Both can be increased with the addition of deployable solar arrays]
Payload Visibility	Unobstructed Field of View for payloads is possible
Platform Mass	50 – 150 kg
Stabilization mode	3-axis stabilization
Redundancy	Dual Redundant Systems
Attitude	Attitude Error Knowledge: 10 arcsec / Attitude Error Control: 0,07° / Attitude Error Rate Stability: 1 arcsec/s / Attitude Modes: Primary Earth Referenced (Intertial Referenced platforms available)
Communication	CAN bus standard for TM & TC data interface, Customer defined interfaces supported / Gbps payload data bus direct to data storage and/or high speed downlink
Orbit	Low Earth Orbit altitudes at sun synchronous inclinatios (non-sun synchronous inclination platforms available)
Designed Life	5-7 years

Related Launch Vehicle: None (However SSTL offers launch contract negotiation)

http://www.sstl.co.uk/Products/EO---Science-Platforms
http://www.sstl.co.uk/Downloads/Brochures/SSTL-X50-Brochure-Jun-14-Web

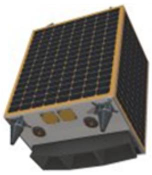
SSTL-X50 Series Platform with EarthMapper Instrument

Satellite Mass	50 kg
Applications	Mapping, agricultural monitoring, flood monitoring, water quality, disaster management, national and urban mapping
Redundancy	Dual Redundant Systems
Communication	Downlink: 80-160 Mbps
Orbit	686 km, SSO, 10:30 am LT
Designed Life	5 to 7 years
Data Storage	256 GB
Compression Ratio	Lossless up to 2,5:1 / Lossy at higher ratios
Data products	Radiometrically and geometrically calibrated
Spectral Bands	525-605 nm (Green) / 630-690 nm (Red) / 774-900 nm (NIR)
GSD	22 m
Swath	650 km
SNR	All bands > 100:1
Raw Digitisation	8-14 bits

Related Launch Vehicle: None (However SSTL offers launch contract negotiation)

http://www.sstl.co.uk/Products/EO---Science-Platforms
http://www.sstl.co.uk/Downloads/Brochures/SSTL-X50-Brochure-Jun-14-Web

SSTL-X50 Series Platform with TrueColor Instrument

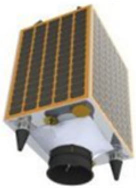


Satellite Mass	75-150 kg (dependent on configuration)
Applications	Mapping, vegetation mapping, high accuracy land cover assessments, flood monitoring, water quality, disaster management, national and urban mapping, geological mapping
Redundancy	Dual Redundant Systems
Communication	Downlink: 80-500 Mbps
Orbit	700 km, SSO, 10:30 am LT
Designed Life	5 to 7 years
Data Storage	Up to 1 TB
Compression Ratio	Lossless up to 2,5:1 / Lossy at higher ratios
Data products	Radiometrically and geometrically calibrated
Spectral Bands	450-515 nm (Blue) / 525-605 nm (Green) / 630-690 nm (Red) / 774-900 nm (NIR) / 1550-1750 nm (SWIR)
GSD	5,25 m (Visible, NIR bands) / 19 m (SWIR band)
Swath	390 km (all bands)
SNR	All bands > 100:1
Raw Digitisation	8-14 bits

Related Launch Vehicle: None (However SSTL offers launch contract negotiation)

http://www.sstl.co.uk/Products/EO---Science-Platforms
http://www.sstl.co.uk/Downloads/Brochures/SSTL-X50-Brochure-Jun-14-Web

SSTL-X50 Series Platform with Precision Instrument



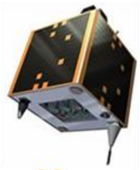
Satellite Mass	60-150 kg (dependent on configuration)
Applications	Mapping, agriculture, insurance, natural resource, financial and economic modelling, consumer media
Redundancy	Dual Redundant Systems
Communication	Downlink: 80-500 Mbps
Orbit	500 km, SSO, 10:30 am LT
Designed Life	5 to 7 years
Data Storage	Up to 1 TB
Compression Ratio	Lossless up to 2,5:1 / Lossy at higher ratios
Data products	Radiometrically and geometrically calibrated
Capture Modes	HD Video and Still Capture
Spectral Bands	HD Video: PAN or Colour / Still: Red-Green-Blue-NIR
GSD	HD Video: 1 m / Still R-G-B-NIR: 0,7 m
Swath	17 km
Raw Digitisation	8-14 bits
Satellite Agility	+/- 20° roll
Field of Regard	365 km

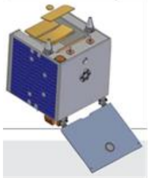
Related Launch Vehicle: None (However SSTL offers launch contract negotiation)

http://www.sstl.co.uk/Products/EO---Science-Platforms
http://www.sstl.co.uk/Downloads/Brochures/SSTL-X50-Brochure-Jun-14-Web

SSTL-100 Series Platform with Payload

SURREY SATELLITE TECHNOLOGY LTD





	SSTL-100	SSTL-100 v3.0
Satellite Mass		100 kg
Applications	Mapping, agricultural monitoring (subsidies and insurance), flood monitoring, water quality, fire hazard detection, disaster monitoring, relief agency support	Mapping, agricultural monitoring, flood monitoring, water quality, disaster management, national and urban mapping, geological mapping, vegetation mapping, high accuracy land cover assessments
Communications	Encryption of all TM/TC links / Data encryption	
Orbit		703 km, SSO, 10:30am LTAN
Designed Life	5 years	
Data Products	Radiometric and Geometric calibrated images	
Spectral Bands	Red, Green, NIR	450-515 nm (Blue) / 525-605 nm (Green) / 630-690 nm (Red) / 774-900 nm (NIR) / 1550-1750 nm (SWIR)
GSD	22 m (Multispectral)	10-15 m (VIS/NIR) / 20-30 m (SWIR)
Swath	600 km	440 km
SNR		All bands > 100:1
Delivery Schedule	18 months	

Related Launch Vehicle: None (However SSTL offers launch contract negotiation)

http://www.sstl.co.uk/Downloads/Datasheets/SSTL-100
http://www.sstl.co.uk/Products/EO---Science-Platforms
http://www.sstl.co.uk/Downloads/Datasheets/1727-SSTL-100-V3-Datasheet

SSTL-150 Series Platform with Payload

SURREY SATELLITE TECHNOLOGY LTD

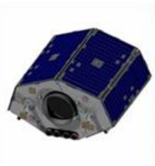
Applications	Surveillance, multi-angle measurements, national and urban mapping, agricultural monitoring, precision farming, security, orthographic mapping
Communications	Encryption of all TM/TC links / Payload data encryption Real-time downlink or store and forward
Designed Life	7 years
Data Products	Hyperspectral datacube / Radiometric and Geometric calibrated images
Spectral Bands	Red, Green, NIR, Panchromatic
GSD	No info for Wide area multispectral plus 2,5 m panchromatic (PAN) + 5 m multispectral (MS) or 17 m hyperspectral (HS)
Swath	600 km (wide area multispectral) / 20 km (for 2,5 m PAN & 5 m MS) / No info (HS)
Delivery Schedule	24 months
Fligh Experience	Beijing-1 (SSTL-150i), SSTL-150i 2,5 m resolution, SSTL-150 RapidEye
Other features	30° off-track pointing

Related Launch Vehicle: None (However SSTL offers launch contract negotiation)

http://www.sstl.co.uk/Products/EO---Science-Platforms
http://www.sstl.co.uk/Downloads/Datasheets/SSTL_150-Feb-09

SSTL-300 Series Platform with Payload

SURREY SATELLITE TECHNOLOGY LTD



	SSTL-300	SSTL-300 S1
Satellite Mass		350 kg
Applications	Surveilance, security, multi-angle measurements, national and urban mapping, agricultural monitoring, precision farming, orthographic mapping	Surveillance, security, multi-angle measurements, national and urban mapping, agricultural monitoring, precision farming, orthographic mappic
Communications	Encryption of all TM/TC links / Payload data encryption / Real-time downlink or store and forward	Encryption of all TM/TC links / Payload data encryption
Orbit		500 km, SSO, 10:30am LTAN
Designed Life	7 years	
Data Products	Radiometric and Geometric calibrated images / Stereo / Wide area	
Spectral Bands	Blue, Red, Green, Near IR, Panchromatic	
GSD	1,5-2,5 m (PAN) / > 4 m (MS) / No info (wide area multispectral)	0,75 m (PAN) / 3 m (MS)
Swath	No info (PAN & MS) / 300 km (wide area multispectral)	17 km
Digitisation		10 bits
SNR		All bands > 100:1
MTF		10% (at Nyquist)
Compression		JPEG-LS configurable
Revisit	Coverage/revisit 2 days worldwide	
Delivery Schedule	24 months	
Other features	Fast slew, 45° off-track pointing	

http://www.sstl.co.uk/Downloads/Datasheets/SSTL_300
http://www.sstl.co.uk/Downloads/Datasheets/SSTL-300-S1-Datasheet-pdf

Related Launch Vehicle: None (However SSTL offers launch contract negotiation)

NovaSAR-S Synthetic Aperture Radar Platform + Payload

Satellite Mass	< 500 kg
Applications	Flood monitoring, agricultural crop assessment, forest monitoring (temperate and rain forest), land use mapping, disaster management, maritime applications (e.g. ship detection and oil spill monitoring)
Redundancy	
Communication	500 Mbps downlink rate / S-Band (2025-2110 MHz, 2200-2290 MHz) TTC Frequency Band / X-Band (8,025-8,4 GHz) Downlink frequency
Orbit	580 km (SSO or Low Inclination Equatorial orbit)
Designed Life	7 years
Antenna	Microstrip patch phased array (3m x 1m)
Peak RF Power	1,8 kW
Payload Duty Cycle	At least 2 minutes per orbit (single image > 800 km long)
Payload Imaging Modes	ScanSAR, Maritime Surveillance, Stripmap, ScanSAR (wide)
Imaging frequency band	S-Band (3,1-3,3 GHz)
Number of Phase Centers	18
Imaging polarisations	Single, dual, tri or quad polar (HH, HV, VH, VV)
Spatial Resolution	6 m (ScanSAR) / 30 m (Maritime Surveillance) / 6 m (Stripmap) / 30 m (ScanSAR)
Swath	100 km (ScanSAR) / 750 km (Maritime Surveillance) / 15-20 km (Stripmap) / 140 km (ScanSAR)
Payload Data Memory	544 GB
Propulsion System	Xenon
Delivery Schedule	24 months

Related Launch Vehicle: None (However SSTL offers launch contract negotiation)

http://www.sstl.co.uk/Downloads/Datasheets/1767-SSTL-SAR-Datasheet
http://www.sstl.co.uk/Downloads/Brochures/2881-SSTL-NovaSAR-Brochure

As the market leader in payload manufacturing, Thales Alenia Space can provide all types of missions.

They offer:

- **Complete satellites**
- **Platforms**
- Observation payloads (**Optical** and **Radar**)

Flight experience: Cosmo-SkyMed, German SAR-Lupe (SAR instrument), Kompsat-5 (SAR instrument)

https://www.thalesgroup.com/en/thales-alenia-space
https://www.thalesgroup.com/sites/default/files/asset/document/SAR_Imaging_Processing092012.pdf
https://www.thalesgroup.com/sites/default/files/asset/document/Data_Compression-Processing2012.pdf

PROTEUS LEO PLATFORM

Payload Mass	300 kg
Payload Power	300 W
Memory	2 Gigabits
Telemetry	S-band
Data Rate	690 kbps
Orbit	600 to 1500 km (Drifting, sun synchronous, near-equatorial orbits)
Pointing	Earth, anti-Earth, intertial, follow-up of any guiding predefined profile
Pointing accuracy	0,02 to 0,05° (mission dependant)
Life	Around 5 years
Delivery Time	27 months
Interfaces	Standard mechanical and electrical interfaces
Flight Experience	Jason-1, Calypso, Jason-2, Corot, SMOS, MEGHA TROPIQUES

Related Launch Vehicle: 500 kg to 1000 kg class Launch Vehicles

https://www.thalesgroup.com/en/thales-alenia-space
https://www.thalesgroup.com/en/worldwide/space/proteus-leo-platform

Yuzhnoye State Design Office is one of the most well-known and recognized scientific and design companies in the world in the field of space technology development.

They offer:

-**Complete satellites**

-**Launch Services** on Zenit, Dnepr and Cyclone launch vehicles

Flight experience: Sich-1, Sich-2, EgyptSat-1

http://www.yuzhnoye.com/en/company/

http://www.yuzhnoye.com/en/technique/space-vehicles/

http://www.yuzhnoye.com/en/technique/launch-vehicles/launch-services/

SICH-2-1 Satellite

Payload Mass	54 kg
Satellite Mass	180 kg
Applications	Earth Observation
Stabilization mode	3-axis with reaction wheels and magnetic torquers
Attitude	Attitude Control Accuracy: < 0,2 ° (while imaging) and < 5 ° (standby) Maneuver Capacity: ± 35 ° from nadir
Communication	30 Mbps X-Band Data Rate, OQPSK modulation
Orbit	663-682 km, Circular sun-synchronous (~98,1 ° inclination)
Designed Life	5 years
Onboard Data Storage Capability	10 GB
Data Products	Digital visible and infrared images of Earth surface
Spectral Bands	MS: 510-590 nm (Green) / 610-680 nm (Red) / 690-790 nm (NIR) / 800-890 (NIR) / IR: 1510-1700 nm (SWIR)
GSD	MS: 7,8 m (at nadir) / IR: 39,5 m (at nadir)
Swath	MS: 46,6 km (at nadir) / IR: 55,5 km (at nadir)

Related Launch Vehicle: Yuzhnoye offers launch services on Zenit, Dnepr and Cyclone launch vehicles

http://www.yuzhnoye.com/en/technique/space-vehicles/

http://www.yuzhnoye.com/en/technique/space-vehicles/earth-observation/sich-2-1/

SICH-2M Satellite

Payload Mass	206 kg
Satellite Mass	500 kg
Applications	Earth observation
Stabilization mode	3-axis with reaction wheels and magnetic torquers
Attitude	Attitude Control Accuracy: < 0,2 ° (while imaging) and < 5 ° (standby) Maneuver Capacity: ± 40 ° from nadir
Propulsion	Ammonia propulsion system
Communication	320 Mbps Data Rate
Orbit	490 km, Circular sun-synchronous (~97,4 ° inclination)
Designed Life	7 years
Onboard Data Storage Capability	2 TB
Data Products	High-resolution digital visible and infrared images of Earth surface, areal mapping and stereo imaging
Spectral Bands	High Res.: 500-890 nm / MS: 500-590 nm (Green) / 610-680 nm (Red) / 690-790 nm (NIR) / 790-890 (NIR) / IR: 8000-10500 nm / 10500-11500 nm / 11500-12500 nm / 12500-13500 nm
GSD	High Res.: 1,9 m / MS: 5,7 m (at nadir) / IR: 110 m (at nadir)
Swath	High Res.: 68 km (at nadir) / MS: 64 km (at nadir) / IR: 68 km

Related Launch Vehicle: Yuzhnoye offers launch services on Zenit, Dnepr and Cyclone launch vehicles

http://www.yuzhnoye.com/en/technique/space-vehicles/

http://www.yuzhnoye.com/en/technique/space-vehicles/earth-observation/sich-2M/

SICH-3-0 Satellite

Payload Mass	300 kg
Satellite Mass	700 kg
Applications	Earth observation
Stabilization mode	3-axis with reaction wheels and magnetic torquers
Attitude	Attitude Control Accuracy: < 0,05 ° (while imaging) and < 5 ° (standby) Maneuver Capacity: ± 40 ° from nadir
Propulsion	Ammonia propulsion system
Communication	640 Mbps Data Rate
Orbit	490 km, Circular sun-synchronous (~97,4 ° inclination)
Designed Life	7 years
Onboard Data Storage Capability	256 GB
Data Products	Super-resolution digital panchromatic and multispectral images of Earth surface, areal and vector mapping, and stereo imaging
Spectral Bands	PAN: 450-900 nm / MS: 450-510 nm (Blue) / 510-590 nm (Green) / 610-680 nm (Red) / 800-890 (NIR)
GSD	PAN: 0,5 m / MS: 2 m (at nadir)
Swath	Stripmap, spotlight, vector, and stereo imaging: 17 km / areal mapping: 32 km or 47 km

Related Launch Vehicle: Yuzhnoye offers launch services on Zenit, Dnepr and Cyclone launch vehicles

http://www.yuzhnoye.com/en/technique/space-vehicles/

http://www.yuzhnoye.com/en/technique/space-vehicles/earth-observation/sich-3-O/

SICH-3-R Satellite

Payload Mass	230 kg
Satellite Mass	600 kg
Applications	Earth radar observation
Stabilization mode	3-axis with reaction wheels and magnetic torquers
Attitude	Attitude Control Accuracy: < 0,05 ° (while imaging) and < 5 ° (standby)
Propulsion	Ammonia propulsion system
Communication	320 Mbps Data Rate
Orbit	555 km, Circular (~60 ° inclination)
Designed Life	7 years
Onboard Data Storage Capability	128 GB
Data Products	High resolution radar images
Operating Frequency	9,67 GHz (X-Band)
Sweep area	25-45 ° (from nadir)
GSD	Spotlight mode: 2 m x 2 m / Stripmap 1 mode: 2 m x 2 m / Stripmap 2 mode: 2 m x 2 m / ScanSAR mode: 20 m x 20 m [azimuth x sideward]
Swath	Spotlight mode: 10 km x 10,85 km / Stripmap 1 mode: 650 km x 8,5 km / Stripmap 2 mode: 650 km x 24,3 km / ScanSAR mode: 650 km x 57 km [azimuth x sideward]

Related Launch Vehicle: Yuzhnoye offers launch services on Zenit, Dnepr and Cyclone launch vehicles

http://www.yuzhnoye.com/en/technique/space-vehicles/

http://www.yuzhnoye.com/en/technique/space-vehicles/earth-observation/sich-3-r/

ATTACHMENT B - SPSYSE-TK METHODOLOGY DEVELOPMENT

This attachment describes how the SPSYSE-TK methodology was developed from different systems engineering references. It shows the main references where key activities, processes, and ideas came from.

The style of the flowcharts of the SPSYSE-TK methodology were based on the flowcharts of the ECSS-E-10 Part 1B standard (ECSS, 2004).

The execution of a project kick-off at the beginning of the space project was considered from the ECSS-E-10 Part 1B standard (ECSS, 2004).

Beginning the methodology with a mission statement was considered from the Space Mission Analysis and Design (SMAD) book (WERTZ; LARSON, 2005). Furthermore, the task for reviewing the mission statement to understand needs came from suggestions of ECSS-E-10 Part 1B standard (ECSS, 2004) and the Applied Space Systems Engineering (ASSE) book (LARSON et al., 2009).

Splitting the needs analysis first for the customer and then for the mission stakeholders was also considered from the ASSE book (LARSON et al., 2009). Similarly, the idea of splitting the needs analysis first for mission stakeholders and then for the space system stakeholders was considered from INPE’s systems engineering course lectures (LOUREIRO, 2015). This last idea is reinforced by the ISO/IEC/IEEE 15288 standard (ISO et al., 2015a), which describes that new stakeholders might be identified after the initial stakeholders identification when defining the system.

The idea of the sequence of identifying needs, defining mission requirements, establishing a concept of operations, defining space system requirements, and finally, establishing the plans was considered from the ASSE book (LARSON et al., 2009). Furthermore, the relationship among systems engineering information items as described in ‘attachment d - systems engineering fundamentals’ reinforced this sequence.

The idea of defining the space system (and its segments) before assessing feasibility came from the handbook of space technology (LEY et al., 2009). Similarly, the idea of estimating costs and feasibility before a review also came from such handbook. The idea of having a review at the end of phases is also a typical practice that is recommended by NASA and ECSS standards. However, within the SPSYSE-TK methodology, reviews were split in two milestones and one process since that logic describes what in fact occurs in space projects. Objectives of the reviews were established from recommendations of ECSS-M-ST-10-01C standard (ECSS, 2008a). Similarly, the processes added immediately after the reviews were described according to activities suggested by such standard. Finally, the concluding milestones of the phases were described following the logic of the kick-offs described by ECSS-E-10 Part 1B standard (ECSS, 2004) but extended to cover both the closing of the current phase and the start of the subsequent.

The task for identifying the implicit needs from domain knowledge, context understanding, and previously documented gaps came from the ISO/IEC/IEEE 15288 standard (ISO et al., 2015a).

The idea of identifying and resolving ambiguous and inconsistent needs came from the good practices for defining requirements as described by the ISO/IEC/IEEE 15288 and 29148 standards (ISO et al., 2011, 2015a). Inconsistency and ambiguity were considered as the main characteristics that requirements must have within the context of this work to avoid problems.

The idea of classifying needs into essential, conditional, and optional came from the ASSE book (LARSON et al., 2009). Similarly, the idea of ranking conditional needs came from such book. However, it should be noticed that the ASSE book suggests the grouping and ranking of mission requirements. On the other hand, the SPSYSE-TK methodology suggests the grouping of needs and the ranking only of the conditional needs. A ranking among needs is also suggested by the ISO/IEC/IEEE 15288 standard (ISO et al., 2015a).

The idea of establishing requirements (and conditional demands) with critical acceptance criteria (or critical performance measures) came from ISO/IEC/IEEE 15288 standard (ISO et al., 2015a) and the ASSE book (LARSON et al., 2009). However, in the SPSYSE-TK methodology, the term used was technical measures according to the INCOSE-TP-2003-020-01 (ROEDLER; JONES, 2005). Then, the term 'minimum success criteria' was used for referring to the minimum value that the technical measure shall have to be fulfilled.

The use of 'shall' statements and 'should' statements for referring to mandatory and desirable characteristics are in conformity with the usage suggested by the ECSS-E-ST-10-06C standard (ECSS, 2009c), the ISO/IEC/IEEE 29148 standard (ISO et al., 2011), and the NASA systems engineering handbook (NASA, 2007).

The space system operational concepts and architectures development is mainly based on the ASSE book (LARSON et al., 2009). The definition of operational scenarios (or use case) representing anticipated uses of the space system is also reinforced by the ISO/IEC/IEEE 15288 standard (ISO et al., 2015a). Techniques for characterizing operational concepts and architectures came from ISO/IEC/IEEE 29148 standard (ISO et al., 2011) and ISO/IEC TR 24748-2 technical report (ISO; IEC, 2011).

The idea of performing a planning focused on activities of the following phase as well as estimating programmatic aspects came from the ECSS-E-10 Part 1B standard (ECSS, 2004). Similarly, the idea of splitting feasibility in technical and programmatic came from the ECSS-M-ST-10C Rev. 1 (ECSS, 2009a).

The idea of including a Request For Information (RFI) and a Request For Proposal (RFP) was considered from the handbook of space technology (LEY et al., 2009), which describes that commercial programs typically used these tools. This idea was reinforced by recommendations of the reviewers of the preliminary proposal of this dissertation.

Defining that the systems engineering group supports the preparation and distribution of RFIs, RFPs, some plans, and other procurement and development documents instead of being the responsible group came from the ECSS-E-10 Part 1B standard (ECSS, 2004).

The continuous refinement of the space system operational concept, architecture, and requirements is mainly based on the recommendations of the several researches described in section ‘2.3 Systems engineering with the use of commercial products’.

The idea of harmonizing the ground segments characteristics with the space segment characteristics came from the ECSS-E-10 Part 1B (ECSS, 2004).

Examples of the techniques that can be used to gather needs were taken from INPE’s systems engineering course lectures (LOUREIRO, 2015) while techniques for identifying stakeholders were taken from the Burge Hughes Walsh systems engineering tool box (BURGE, 2011). Similarly, techniques for identifying and deriving requirements and conditional demands for the space system as well as the space and ground segments were taken from Halligan (2012).

Techniques listed for selecting among alternatives came from NASA systems engineering handbook (NASA, 2007), NASA systems engineering toolbox (NASA, 1994), and Perrone (2004). However, the suggested technique of assessing the mission utility came from the SMAD book (WERTZ; LARSON, 2005).

Examples of mission goals and space system requirements (including segment and segment systems requirements) were identified from the SMAD book (WERTZ; LARSON, 2005), the handbook of space technology (LEY et al., 2009), and the NASA systems engineering handbook (NASA, 2007).

The methodology was frequently discussed and enriched with contributions and ideas coming from advisors with experience in several INPE’s space missions and with colleagues with experience in systems engineering.

ATTACHMENT C - APPLICATION OF ECSS METHODOLOGY

This attachment presents the application of the ECSS systems engineering methodology within the scope of the SPSYSE-TK methodology described in chapter '3.1 Scope' and in the context of the mission described in section '4.1 Mission Description'.

Due to the scope of this work and the methodology proposed herein, the author analyzed the ECSS methodology, focusing on its processes, the activities within them, and the essential content that they produce rather than on the specific documentation that such processes produce.

The analysis of the ECSS methodology involved mainly the following ECSS standards: ECSS-E-10 Part 1B (ECSS, 2004), ECSS-E-ST-10C (ECSS, 2009b), ECSS-E-ST-10-06C (ECSS, 2009c), ECSS-M-ST-10C (ECSS, 2009a), ECSS-M-ST-10-01C (ECSS, 2008a), ECSS-S-ST-00C (ECSS, 2008c), and ECSS-S-ST-00-01C (ECSS, 2012).

The phases of the ECSS systems engineering methodology that the author identified to be within the scope of this work are the phases 0, A, B, and C. Figure C.1 illustrates the name and sequence of such phases.

Figure C.1 - ECSS phases within the scope of this application.

Phase 0	*Phase A*	*Phase B*	*Phase C*
Mission analysis/need identification	**Feasibility**	**Preliminary definition**	**Detailed definition**

Source: Adapted from ECSS (2009a).

During the analysis of the ECSS methodology, the author observed that the ECSS-E-10 Part 1B standard refers to the terms functional specification and technical specification as different. However, the subsequent version of such standard, ECSS-E-ST-10C (ECSS, 2009b), together with the ECSS-E-ST-10-06C (ECSS, 2009c) standard state that both terms were simplified so they shall be called instead as technical requirements specification. Furthermore, due to the focus on essential content rather than on documents, the author uses within this application of the ECSS the term technical requirements when describing a process or activity related to the functional specification, technical specification, or technical requirements specification. Technical requirements in accordance with the ECSS-E-ST-10-06C standard represent functional, mission, interface, environmental, operational, human factor, integrated logistics support, physical, product assurance induced, configuration, design, and verification requirements, excluding other requirements such as cost, methods of payment, quantity required, time, and place of delivery.

The following sections contain a description of each of the aforementioned phases and the processes that should be implemented within each phase in the context of the described mission.

C.1 **Phase 0: mission analysis/needs identification**

C.1.1 Phase 0 objectives

The main objective of this phase is to define a mission and propose possible associated system concepts.

The specific objectives of this phase within the systems engineering effort are:

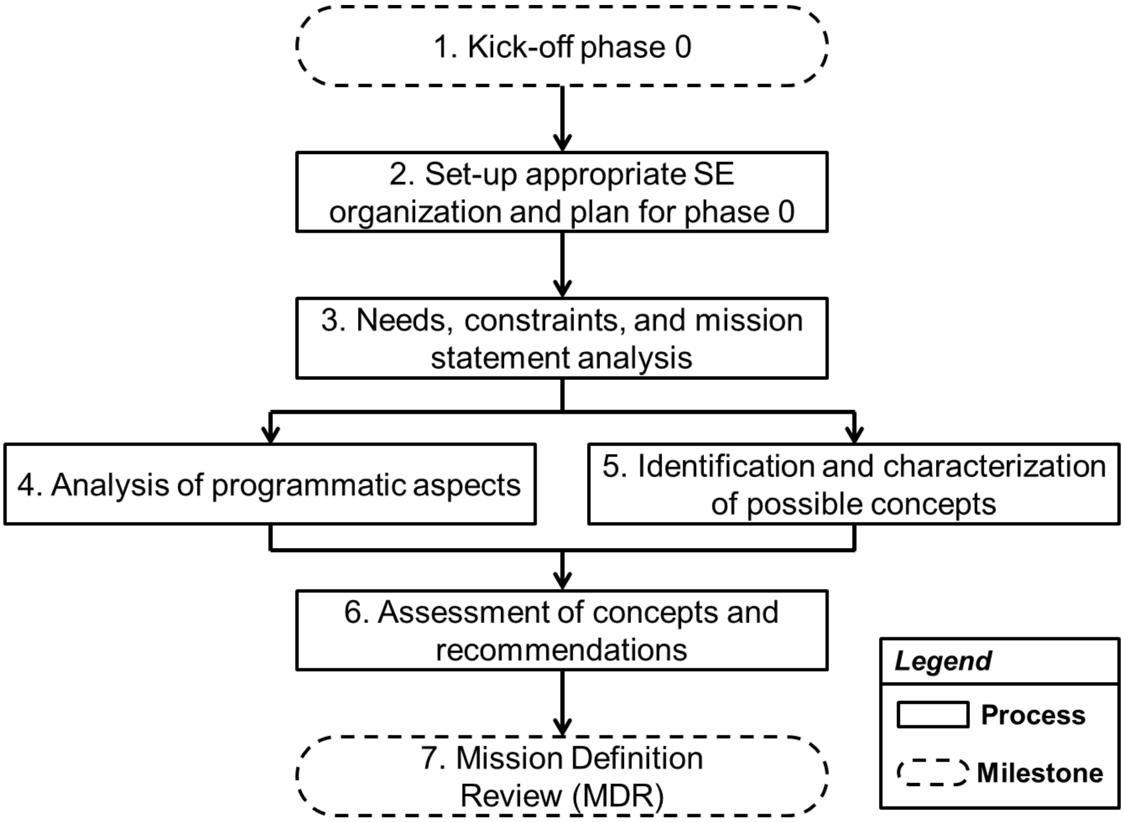
- Support the identification and characterization of the mission needs, expected performance, goals, and operating constraints declared in the mission statement;
- Develop technical requirements;
- Perform a preliminary assessment of programmatic aspects supported by market and economic studies as appropriate;
- Identify and propose possible mission concepts.

C.1.2 Phase 0 processes and milestones

The author analyzed the objective of each of the processes and milestones within this phase to identify if any of them would not be appropriate within the scope of this work and the particular application case.

After the analysis, the author determined that all processes and milestones of this phase could be applied within this application case. Figure C.2 shows the flowchart of the phase 0 of the ECSS methodology. Rectangle boxes indicate processes, while rounded boxes with dashed lines indicate milestones (e.g. reviews). Processes that are in parallel or in series can (and ideally, should) involve iterations between them.

Figure C.2 - Phase 0 of the ECSS systems engineering methodology.



Source: Adapted from ECSS (2004).

Following subsections describe the objectives and the applicable activities for each applicable process and milestone within this phase.

C.1.2.1 Kick-off phase 0

The primary objectives of this milestone are:

a. Verify that all conditions for the initiation and execution of the phase are agreed and met;
b. Obtain authorization to proceed.

For the ARD-SM, this milestone might consist in a meeting to sign some agreement documents among the organizations and groups participating in the project.

C.1.2.2 Set-up appropriate SE organization and plan for phase 0

This process consists in defining the systems engineering plan for the full project but with focus on the phase 0.

Specifically, this process should include the following task:

a. Prepare the systems engineering plan by tailoring.

For the ARD-SM, task a. might consist in the systems engineering group analyzing the ECSS methodology, especially the phase 0, and tailoring it for the current mission. Then, the systems engineering group might have determined that it would follow the flowchart as described by the ECSS standards (Figure C.2). The systems engineering group might also have identified and supported the definition of the project phases and reviews as well as a preliminary estimate of the duration of such phases. It is assumed that the project phases and reviews were decided to be the same as established by the ECSS standards.

C.1.2.3 Needs, constraints, and mission analysis

This process consists in defining the first the system technical requirements.

Specifically, this process should include the following tasks:

a. Review the mission statement and other existing documents to identify and comprehend the needs and constraints;
b. Derive a first version of technical requirements (e.g. functional, configuration, interface, environmental, and operational);
c. Obtain agreement of the management group and the customer organization on the system technical requirements to avoid any misunderstanding and clarify the major concept driving the expressed needs;
d. Refine the mission statement by iterating the needs-requirement identification loop with support of the customer.

For the ARD-SM, task a. might consist in analyzing the needs and constraints declared by the Ministry of the Environment to answer several issues such as the following:

- What are the boundaries of the Brazilian Legal Amazon rainforest?
- What is the typical area of deforested regions?
- What type of deforestation techniques the Ministry of the Environment wants to identify (e.g. by cutting or by burning)?
- What level of deforestation the Ministry of the Environment wants to identify (e.g. shallow cut or forest degradation)?
- How much time does it take typically to deforest an area?
- How much frequent the satellite should revisit the Amazon rainforest?
- Is the 6-days response time enough for taking control actions?
- Are 6 days enough for the satellite send the image to the ground application segment, the ground application segment process the image, and deliver a notification to the Ministry of the Environment?

- Why does the Ministry of the Environment want to use a deforestation monitoring system already existing? Why INPE’s monitoring systems?
- How do the existing deforestation monitoring systems work?
- What is the status of the VLM?
- What are the characteristics of the VLM?

Then, after understanding the Ministry of the Environment’s needs and constraints, task b. might consist in producing some system technical requirements related to deforested areas characteristics (e.g. spatial resolution, swath), monitoring aspects (e.g. revisit time, latitudes that shall be covered), or related to the interfaces with the existing systems (e.g. INPE monitoring systems, VLM characteristics).

Task c. might consist in showing the system technical requirements to the Ministry of the Environment and to the management group to obtain an agreement from them.

Finally, task d. would consist in producing a refined mission statement with the updated information.

C.1.2.4 Analysis of the programmatic aspects

This process consists in identifying the programmatic aspects and their consequences.

Specifically, this process should include the following tasks:

a. Review existing documents to identify and understand the driving programmatic aspects and constraints;
b. Obtain agreement of the management group on the programmatic aspects;
c. Refine the mission statement by iterating the needs, constraints, and programmatic aspects identification loop with support of customer.

For the ARD-SM, task a. might consist in reviewing the agreement documents signed at the kick-off meeting to response any of the following issues:

- Why the VLM should be used?
- Why the INPE's deforestation monitoring systems should be use?
- Why the overall costs shall not exceed M$100?
- Why the space system shall be operating before January 1, 2022? Why it is preferable before January 1, 2021?
- Why a lifetime of 4 years is the minimum acceptable? Why 5 years would be better?
- How long the current phase should last?
- How long the definition of the space system should last?
- How long the current phase should last?

Such review might have shown that the use of the VLM is a political expectation to gain public visibility or that the use of any of the INPE's deforestation monitoring systems is required to keep the overall costs as low as possible while taking advantage of the already trained staffs of such existing segments. It might also have shown that the current phase should last given months according to the agreement documents.

Task b. would consist in showing the programmatic aspects to the management group to obtain an agreement from such group.

Finally, task c. would consist in refining the mission statement with the updated information. It is assumed that during this loop, it was determined that the use of the VLM was too risky, and consequently, it was taken out from the mission statement.

C.1.2.5 Identification and characterization of possible concepts

This process consists in identifying and characterizing a set of concepts able to fulfill the first version of technical requirements.

Specifically, this process should include the following tasks:

a. Gather information, which can lead to concept definition (e.g. previous experience, R&D output, lessons learned, databases);
b. Define and characterize possible concepts (e.g. technology status and capability, risk analysis);
c. Evaluate roughly the concepts against the main technical requirements (e.g. performance, critical areas);
d. Identify a set of possible concepts.

For the ARD-SM, task a. might consist in reviewing previous and similar remote sensing missions. For instance, such review might have revealed a similar mission as the Deforestation Impact Estimation Project (DEIMES), which targets to obtain information about the environmental impact caused by deforestation and how it evolves over time (GORDON WOOD, 2016).

Then, task b. might have resulted in the definition of three alternatives concepts. The first concept might be a space system with one satellite in sun-synchronous orbit, a ground control segment, and the already existing ground application segment (using DETER system). The second concept might use the PRODES system within the ground application segment instead of the DETER. Finally, the third concept might be a space system with two satellites (both in sun-synchronous orbits), a ground control segment that controls both satellites, and the ground application segment using both the DETER and PRODES systems (being each of these systems only compatible with the data of one of the satellites). Figure 4.3 illustrates the aforementioned first concept.

Task c. would consist in evaluating roughly the three alternative concepts against the technical requirements. The following issues might be assessed for each concept:

- How well the concept would cover the entire Brazilian Legal Amazon rainforest?

- How well the concept would perform in terms of spatial resolution?
- How well the concept would perform in terms of revisit time?
- How well the concept would detect deforestation by cut?
- How well the concept would detect deforestation by burning?

Finally, task d. would consist in identifying possible concepts. It is assumed that all the concepts defined in task b. were assumed to be possible, and thus, they were selected to advance to further processes.

C.1.2.6 Assessment of concepts and recommendations

This process consists in establishing the preliminary technical requirements and proposing a reduced set of recommended system concepts compliant with the mission statement.

Specifically, this process should include the following tasks:

a. Compare the possible concepts regarding objective and constraints;
b. Rank the possible concepts.

According to author's interpretation, the comparison of the concepts regarding objective and constraints would mean to compare them in terms of technical and programmatic aspects. Then, task a. for the ARD-SM might have resulted in a comparison as Table C.1 shows.

Table C.1 - Possible concepts comparison.

	Concept #1	Concept #2	Concept #3
Pros	-Medium fulfillment of technical requirements -Ideal for real-time detection	-Medium fulfillment of technical requirements	-Best fulfillment of technical requirements -Ideal for real-time detection
Cons	-	-Not the best for real-time detection	-Costs likely to exceed the imposed limit

Source: Author production.

Then, task b. might have consisted in ranking the possible concepts as follows:

1. Concept #1;
2. Concept #2;
3. Concept #3.

C.1.2.7 Mission Definition Review (MDR)

The primary objectives of this milestone are:

a. Assess the updated mission statement, the technical requirements, and the programmatic aspects;
b. Identify problems and questions;
c. Recommend actions or solutions;
d. Implement actions;
e. Release the updated mission statement.

For the ARD-SM, this milestone might consist in a review made by an experienced group of specialists. It is assumed that they provide some recommendations that are accepted by the organizations and groups participating in the project, and thus, the outcomes of this phase are updated.

C.2 **Phase A: feasibility**

C.2.1 Phase A objectives

The main objective of this phase is to finalize the expression of the needs identified in phase 0 and propose solutions to meet the perceived needs.

The specific objectives of this phase within the systems engineering effort are:

- Elaborate possible system and operations concepts and system architectures;
- Compare the possible system and operations concepts against the identified needs, to determine levels of uncertainty and risks;

- Establish the functional decomposition;
- Assess the technical and programmatic feasibility of the possible concepts by identifying constraints relating to implementation, costs, schedules, organization, operations, maintenance, production, and disposal;
- Identify critical technologies and propose pre-development activities;
- Quantify and characterize critical elements for technical and economic feasibility;
- Propose technical solutions for the possible system and operations concept(s);
- Establish the preliminary systems engineering plan[4] for the project.

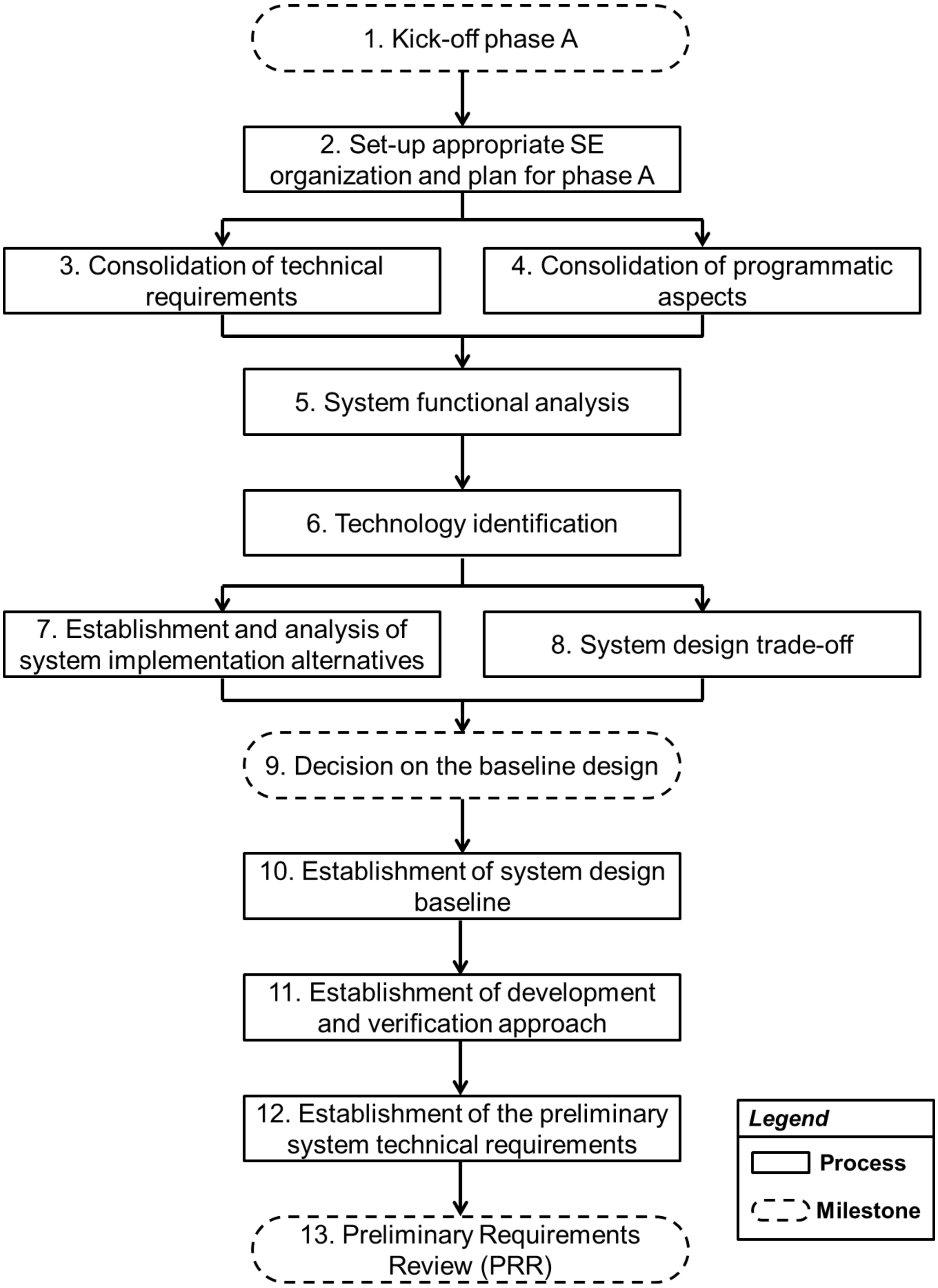
C.2.2 Phase A processes and milestones

The author analyzed the objective of each of the processes and milestones within this phase to identify if any of them would not be appropriate within the scope of this work and the particular application case.

After the analysis, the author determined that all processes and milestones of this phase could be applied at least to a certain extent within this application case. The extent of their application, incompatibilities, and required reinterpretations are later described. Figure C.3 shows the flowchart of the phase A of the ECSS methodology. Rectangle boxes indicate processes, while rounded boxes with dashed lines indicate milestones (e.g. reviews). Processes that are in parallel or in series can (and ideally, should) involve iterations between them.

[4] The establishment of the preliminary management plan and the product assurance plan are also among the objectives of this phase. However, they are outside of the scope of this work.

Figure C.3 - Phase A of the ECSS systems engineering methodology.



Source: Adapted from ECSS (2004).

Following subsections describe the objectives and the applicable activities for each applicable process and milestone within this phase.

C.2.2.1 Kick-off phase A

The primary objectives of this milestone as well as its activities and their application on the ARD-SM would be similar to the ones described previously in section ‘C.1.2.1 Kick-off phase 0’.

C.2.2.2 Set-up appropriate SE organization and plan for phase A

The objective of this process as well as its activities and their application on the ARD-SM would be similar to the ones described previously in section ‘C.1.2.2 Set-up appropriate SE organization and plan for phase 0’. However, the systems engineering plan herein refined would focus on the current phase instead. Consequently, for the ARD-SM, the systems engineering group might have determined that it would follow the flowchart as described by the ECSS standards (Figure C.3).

C.2.2.3 Consolidation of technical requirements

This process consists in consolidating the preliminary system technical requirements on the basis of all updates and clarifications provided by the customer organization during the kick-off meeting.

Specifically, this process should include the following tasks:

a. Review the preliminary technical requirements in order to confirm, clarify, or extend them;
b. Consolidate the preliminary technical requirements;
c. Obtain agreement of the management and the customer organizations on the system technical requirements to avoid any misunderstanding.

For the ARD-SM, tasks a. and b. would consist in reviewing the preliminary technical requirements. Such review might cause an update of some of the previously defined requirements (e.g. spatial resolution, swath, revisit time, interfaces).

Task c. might consist again in showing the system technical requirements to the Ministry of the Environment and to the management group to obtain an agreement from them.

C.2.2.4 Consolidation of programmatic aspects

This process consists in consolidating the programmatic aspects and their consequences on the basis of all updates and clarifications provided by the customer organization during the kick-off meeting.

Specifically, this process should include the following tasks:

a. Review the programmatic aspects and constraints in order to confirm, clarify, or extend them;
b. Consolidate the programmatic aspects;
c. Obtain agreement of the management group on the programmatic aspects.

For the ARD-SM, tasks a. and b. would consist in reviewing the programmatic aspects and constraints and updating them if required (e.g. cost of the system, launch date).

Task c. might consist again in showing the programmatic aspects to the management group to obtain an agreement from such group.

C.2.2.5 System functional analysis

This process consists in defining one or more functional architectures (logical solution representations) that conform to the consolidated technical requirements.

Specifically, this process should include the following tasks:

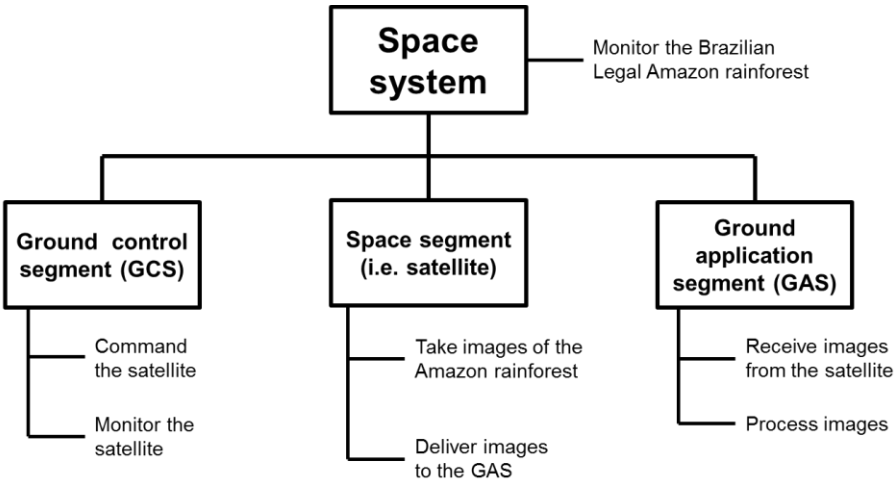
a. Establish system functional architectures (logical solution representations);

b. Allocate system technical requirements to the various logical elements of the functional architectures;
c. Define lower level technical requirements.

It should be highlighted that this process and its tasks according to author’s criteria would be more appropriate for the development of new individual systems. Functional architectures, allocation of requirements to functional elements, and the definition of lower levels make more sense in such context. Furthermore, ECSS-E-10 Part 1B standard does not describe up to which lower level the functional architectures should go. In the context of this work, this process is somewhat incompatible so it cannot be applied without an interpretation by the systems engineering group. Consequently, the following paragraphs show an author’s interpretation of how this process and its tasks might be applied within the scope of this work. Within this interpretation, the depth of functional analysis would make only sense if performed up to the identification of functions of the segments systems (e.g. satellites, ground stations, control center, mission operations center). It should be noticed that functional analysis might also be applied at lower levels for the ground segments systems within the development effort. However, in such cases and in accordance with the premises of the space projects within the scope of this work, this process would be implemented by the responsible of the development of the ground segment systems and not by the systems engineering group.

Within the aforementioned context and for the ARD-SM, part of the tasks a., b., and c. might be already performed when the concepts were defined in the previous phase. When the concepts were defined, an architecture (both physical and functional) was assumed for the space system. As Larson et al. (2009) state, it is typical to have a generic architecture when partitioning systems. In space systems, especially when the space segment is orbiting the Earth (i.e. satellite systems), this would be especially true. Specifically, it was defined that the space system would have a satellite that would take the images, a ground control segment that would control the satellite, and a ground application segment that would receive and process the images coming from the satellite. Figure C.4 shows the architecture and some of the already conceived functions for each element.

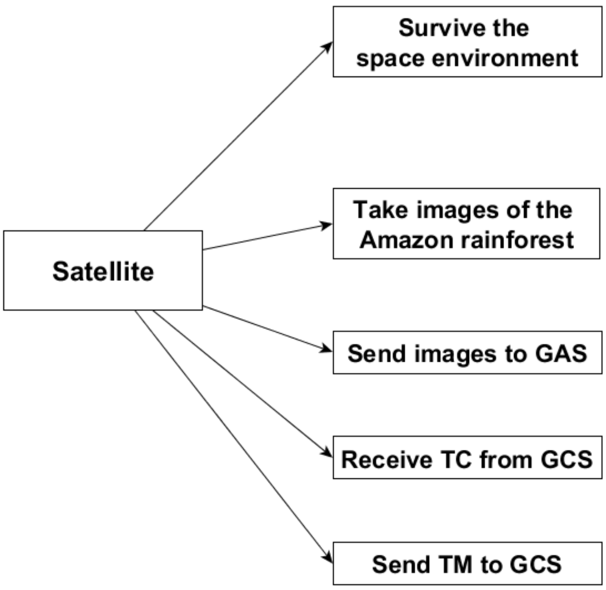
Figure C.4 - Space system architecture and main functions of each elements.



Source: Author production.

Figure C.5 shows an example of a further functional decomposition that might have resulted from the functional analysis at a segment-system level, specifically for the satellite of the ARD-SM space system.

Figure C.5 - Functional decomposition for the satellite.



Source: Author production.

C.2.2.6 Technology identification

This process consists in identifying and characterizing concepts and related physical elements capable of implementing individual functions and conforming to the associated technical requirements for the functional architectures.

Specifically, this process should include the following tasks:

a. Identify alternative implementation concepts for the individual system functions defined in the functional architectures;
b. Identify physical elements enabling the implementation of these concepts;
c. Assess qualitatively the technologies of individual design options, with respect to maturity, availability and development uncertainty, and risk.

It should be highlighted that this process and its tasks according to author's criteria would be more appropriate for the development of new individual systems. The identification and assessment of technology can be appropriate when alternative solutions are available for implementing a specific function. This makes more sense for the development of subsystems or equipment. In the context of this work, this process is incompatible with the use of turnkey satellites. At maximum, this process might be applicable for the ground segments systems that are within the development effort if alternative solutions exist. However, within such case and in accordance with the premises of the space projects within the scope of this work, this process would be implemented by the responsible of the development of the ground segment systems and not by the systems engineering group.

C.2.2.7 Establishment and analysis of system implementation alternatives

This process consists in establishing and analyzing a set of system implementation alternatives on the basis of the identified concepts, technologies, and related elements, and preparing the associated data for their trade-off.

Specifically, this process should include the following tasks:

a. Establish feasible overall system implementation alternatives on the basis of the functional architecture alternatives;
b. Detail the system implementation alternatives down to the next lower level to achieve overall system optimization;
c. Define an appropriate and consistent margin philosophy for technical budgeting purposes;
d. Establish all major system budgets;
e. Identify and assess any development and procurement risk (performance, schedule, cost) in cooperation with product assurance and management groups;
f. Assess the compliancy of each candidate system with respect to the consolidated preliminary technical requirements and the robustness of the implementation alternatives with respect to changes in such requirements.

It should be highlighted that this process and its tasks according to author's criteria would be more appropriate for the development of new individual systems. Mainly, the establishment of implementation alternatives on the basis of functional architectures, the detailing of lower levels for achieving system optimization, and the establishment of margin policies and budgets make more sense for the development of subsystems or equipment. In the context of this work, this process is incompatible with the use of turnkey satellites. At maximum, this process might be applicable for the ground segments that are within the development effort if alternative solutions exist at subsystem- or equipment-levels. However, within such case and in accordance with the premises of the space projects within the scope of this work, this process would be implemented by the responsible of the development of the ground segment systems and not by the systems engineering group. In the context of this work, this process might be reinterpreted by the systems engineering group to be applicable. Consequently, the following paragraphs show an author's interpretation of how this process and its tasks might be applied within the scope of this work.

Within this reinterpretation, the system implementation alternatives might be considered at the highest levels of the space system hierarchy, covering details up to the segment systems-level. Then, for the ARD-SM, task a. might have resulted in the definition of an overall system implementation alternative (i.e. system implementation alternative #1) based on the concept #1 previously described. The system implementation alternative #1 might have presented the following characteristics:

- Satellite:
    - Payload: multispectral and panchromatic camera,
    - Images data link: X-band,
    - Telemetry/Telecommand (TM/TC) link: S-band;
- Ground control segment:
    - Ground station:
        - Antenna: parabolic reflector,
        - TM/TC link: S-band,
        - Link to control center: dedicated optical fiber link;
    - Control center:
        - Link to ground station: dedicated optical fiber link,
        - Link to ground application segment: Internet;
- Ground application segment: DETER system and CBERS and Landsat ground stations and networks.

Other overall system implementation alternatives should have been proposed within this task. For instance, a second alternative (i.e. system implementation alternative #2) related also to concept #1 might have proposed the use of only a panchromatic camera. A third alternative (i.e. system implementation alternative #3) might have presented characteristics similar to the implementation alternative #1 but related to concept #3, so it would consider the use of two satellites and the use of both DETER and PRODES systems. Other alternatives might have proposed the use of an additional infrared camera or the use of the PRODES system in the ground application segment in accordance with concept #2.

Task b. would consist in adding details to the system implementation alternatives in order to optimize the overall design of the alternative. According to author's criteria and within the scope of this work, this task in the context of the ARD-SM might add details to the system implementation alternative #1 that was described above. For instance, the multispectral bands and the panchromatic band that are required for the payload camera might be detailed (e.g. green 520-590 nm, red 620-680 nm, and visible 510-850 nm). Other example might be adding details to the frequency of the TM/TC link (e.g. 2.7 GHz for downlink and 3.1 GHz for the uplink). This task, according to author's criteria, should be performed for each system implementation alternative.

Tasks c. and d. would consist in defining a margin philosophy and the major system budgets. This is typical for the development of new systems. Within the reinterpretation herein, the margin philosophy should allow flexibility to accommodate turnkey satellites. On the other hand and according to ECSS standards, the major system budgets, which are estimated allocations for key parameters, are typical related to parameters such as mass, cost, power, link performance, on-board computer memory capacity. In the context of the ARD-SM and within the scope of this work, some key parameters might be the cost of each segment system or the communications budget. Consequently, a budget might be established for each of those key parameters indicating their expected values and margins. For instance, the satellite might be limited to a cost of M$45 with a margin of M$5, the ground station of the ground control segment to a cost of M$35 with a margin of M$5, and so on. It should be noticed that budgets related to the mass or power would not make sense within the scope of this work. Since the turnkey satellites will be procured, it will be responsibility of the satellite manufacturer to ensure that the satellite have enough power and mass to fulfill the requirements.

According to author's criteria, tasks c. and d. might be performed for each system implementation alternative, especially if the alternatives are very different in terms of their features.

Task e. would consist in assessing the system implementation alternatives in terms of the development and procurement risk. For the ARD-SM, this assessment might have shown that using an alternative with an infrared camera may exceed the cost limits imposed by the Ministry of the Environment. The assessment might also have shown that the alternative that uses the PRODES system would require the development of a software for processing images and detecting real-time deforestation, which would result in exceeding the established deadline or failing the fulfillment of requirements. This task should be performed for each system implementation alternative.

Finally, task f. would consist in assessing the compliancy of each candidate system with respect to the technical requirements and the robustness of the implementation alternatives with respect to changes in such requirements. The assessment of the compliancy with technical requirements might be performed by value analysis according to the standard (to determine the best performance-cost alternatives). For the ARD-SM, this assessment might have revealed that an alternative with a panchromatic camera would provide the best performance-cost trade-off. However, such assessment might also have revealed that such implementation would not be robust in case that the Ministry of the Environment determines in a subsequent stage that deforestation by burning techniques will be more important than deforestation by cut.

C.2.2.8 System design trade-off

This process consists in comparing and ranking the system implementation alternatives as well as identifying a potential system design baseline and options.

Specifically, this process should include the following tasks:

a. Define ranking criteria (technical, financial, and programmatic) and weighting factors;
b. Perform evaluation of criteria for each implementation alternative;
c. Compare the system implementation alternatives;
d. Recommend a system design baseline and options.

It should be highlighted that the tasks established within this process are typically implemented for the comparison and ranking of different implementation alternatives at subsystem- or lower levels. However, due to the reinterpretation of previous processes in which was assumed that the implementation alternatives cover details of the highest levels of the space system up to the segment systems-level, this process could be applied within the scope of this work. Following paragraphs show the application of this process in accordance with the performed reinterpretation.

For the ARD-SM, task a. might have consisted in assigning weighting factors to the degree in which requirements would be fulfilled (e.g. a weighting factor of 10), to the robustness of the alternative in terms of change in the requirements (e.g. a weighting factor of 7), and to the cost of the alternative (e.g. a weighting factor of 5). Then, tasks b. and c. might have resulted in a numerical comparison among the alternatives that in a simplified way might look as Table C.2 shows.

Table C.2 - System implementation alternatives comparison.

	Alternative#1	Alternative#2	Alternative#3
Fulfillment of technical requirements (x10)	8	9	10
Robustness against changes in requirements(x7)	7	5	7
Cost (x5)	10	10	1
TOTAL	179	175	154

Source: Author production.

For the ARD-SM, task d. might have resulted in the recommendation of the system implementation alternative #1 as a system design baseline. A basic description of the implementation alternative #1 was provided in the previous process ‘C.2.2.7 Establishment and analysis of system implementation alternatives’. This task might also have resulted in the recommendation of the alternative #2 as an option and the recommendation of discarding the alternative #3.

C.2.2.9 Decision on the baseline design

The objective of this milestone is:

a. Select the system design baseline.

Similarly to the previous process, it should be noticed that this milestone is considered to be applicable due to the previously performed reinterpretation. Following paragraph shows the application of this milestone in accordance with the performed reinterpretation.

For the ARD-SM, this milestone might consist in a presentation of the system design trade-off to the management group. At the end of this presentation, the management group might have accepted the recommendations and consequently, it might have established formally the alternative #1 as the system design baseline.

C.2.2.10 Establishment of system design baseline

This process consists in defining and refining the design of the selected baseline.

Specifically, this process should include the following tasks:

a. Refine the system design baseline (for the system and the support equipment) down to next lower level, in terms of functions breakdown, physical configuration, product physical breakdown, budgets and appropriate margin philosophy, production, operations (on board and ground), and logistics, while considering management (e.g. industrial policy) aspects;
b. Perform analyses while considering relevant analyses from product assurance (e.g. FMECA).

Similarly to the previous process, it should be noticed that this process is considered to be applicable due to the previously performed reinterpretation. Following paragraph shows the application of this process in accordance with the performed reinterpretation.

For the ARD-SM, task a. would refine the system design baseline. The spatial resolution, the spectral bands of the payload, the preliminary orbit, or any other technical requirement might be refined. Some of the previously established margins or budgets might also be reduced due to a more mature knowledge about the system. Consequently, this task might have led to refine the cost allocated to the satellite to M$47 with a margin of M$2 instead of previous values.

For the ARD-SM, task b. might have included some orbital analysis to confirm and refine some of previously defined characteristics of the orbit (e.g. inclination, semi-major axis, and the Local Time of Descending Node or LTDN).

C.2.2.11 Establishment of development and verification approach

This process consists in establishing the development and verification approach down to the next level.

Specifically, this process should include the following tasks:

a. Establish the systems engineering approach and the related methods and tools for the lower level;
b. Establish the verification approach and related methods;
c. Identify the needs for control plans as appropriate;
d. Implement management (e.g. industrial policy) aspects.

It should be noticed that within the scope of this work, this process is somewhat incompatible. It would not make sense to establish a systems engineering approach at lower levels than the segment systems-level. Furthermore, it would not make sense to prepare a systems engineering approach, methods, and tools for the development of turnkey satellites since it would be responsibility of satellite manufacturer. At maximum, this process might be applicable for the ground segments systems that are within the development effort. However, within such case and in accordance with the premises of the space projects within the scope of this work, this process would be implemented by the responsible of the development of the ground segment system and not by the systems engineering group. However, as it has been done with previous processes, the following paragraphs show an author’s interpretation of how this process and its tasks might be applied within the scope of this work and the previous performed reinterpretations.

For the ARD-SM, all the aforementioned tasks would consist in defining the development and verification approaches for the segment systems according to the system design baseline and the project characteristics. The definition of such approaches and plans might be seen as a refinement of the systems engineering plan that was refined within the ‘C.2.2.2 Set-up appropriate SE organization and plan for phase A’ process.

C.2.2.12 Establishment of the preliminary system technical requirements

This process consists in establishing the preliminary system technical requirements for the system design baseline.

Specifically, this process should include the following task:

a. Establish the preliminary technical requirements on the basis of the preliminary system design baseline and the resulting business negotiation process.

Similarly to the previous processes, it should be noticed that this process is considered to be applicable within the scope of this work due to the previously performed reinterpretation. Following paragraph shows the application of this process in accordance with the performed reinterpretation.

For the ARD-SM, this task would imply the refinement (if needed) of the set of technical requirements that were formerly defined. At the end of this refinement, the technical requirements should be ready to be submitted to the final review of this phase. An example of some of the technical requirements that might have been produced for the satellite of the ARD-SM are the following:

- The satellite shall have a camera and a data transmission equipment for payload data;
- The satellite shall sense in the following spectral bands:
  - Band #1 (green): 520-590 nm;
  - Band #2 (red): 620-680 nm;
  - Band #3 (visible): 510-850 nm.
- The satellite shall transmit data to the ground application segment at a central frequency of 8.2345 GHz;

- The satellite shall transmit data to the ground application segment with a bandwidth of 20 MHz;
- The satellite shall transmit data to the ground application segment at a minimum data rate of 100 Mbps;
- The satellite shall provide a pointing knowledge accuracy of less than 0.1°;
- The satellite shall be capable of executing orbital and attitude maneuvers via telecommand as required;
- The satellite shall be capable of providing enough delta-V to be kept inside a stationkeeping box of less than 1 km per side;
- The satellite shall provide an additional delta-V of 100 m/s for performing manual orbital maneuvers during the lifetime of the satellite, if required;
- The satellite shall keep its equipment within the thermal operation limits;
- The satellite shall provide structural support to all the equipment during its lifetime;
- The satellite shall transmit telemetry data to the ground control segment at a central frequency of 2.7541 GHz;
- The satellite shall transmit telemetry data to the ground control segment with a channel bandwidth of 2 MHz;
- The satellite shall transmit data to the ground control segment at a minimum data rate of 10 Mbps;
- The satellite shall receive data to the ground control segment at a central frequency of 3.1004 GHz;
- The satellite shall provide enough power to any equipment in the satellite during its lifetime;
- The satellite shall be placed in a sun-synchronous orbit of 634.36 km from the Earth surface;
- The orbital parameters of the satellite shall be:
    - Semi-major axis: 7012.5 km;
    - Eccentricity: 0°;
    - Inclination: 98.0216°;

  - Right Ascension of Ascending Node: 96.9093°;
  - Argument of Perigee: 0°.
- The Local Time of Descending Node (LTDN) of the orbit shall be 10:24.

C.2.2.13 Preliminary Requirements Review (PRR)

The primary objectives of this milestone are:

a. Assess preliminary technical requirements and plans;
b. Confirm the technical and programmatic feasibility of the system concept(s);
c. Select the system and operations concept(s) and technical solutions;
d. Identify problems and questions;
e. Recommend actions or solutions;
f. Implement actions;
g. Release the preliminary technical requirements and plans.

For the ARD-SM, this milestone might consist in a review made by an experienced group of specialists. It is assumed that they provide some recommendations that are accepted by the organizations and groups participating in the project, and thus, the outcomes of this phase are updated.

C.3 Phase B: preliminary definition

C.3.1 Phase B objectives

The main objective of this phase is to establish the system preliminary definition for the solution selected at end of phase A and demonstrate that the system meets the technical requirements according to the schedule, the budget, the target cost, and the organization requirements.

The specific objectives of this phase within the systems engineering effort are:

- Confirm technical solution(s) for the system and operations concept(s) and their feasibility with respect to programmatic constraints;

- Conduct ‘trade-off’ studies and select the preferred system concept, together with the preferred technical solution(s) for this concept;
- Establish a preliminary design definition for the selected system concept and retained technical solution(s);
- Determine the verification program;
- Identify and define external interfaces;
- Prepare the next level specifications;
- Initiate pre-development work on critical technologies or system design areas when it is necessary to reduce the development risks;
- Finalize the product physical decomposition;
- Finalize the systems engineering plan[5] and other engineering discipline plans.

C.3.2 Phase B processes and milestones

The author analyzed the objective of each of the processes and milestones within this phase to identify if any of them would not be appropriate within the scope of this work and the particular application case.

After the analysis, the author determined that all processes and milestones of this phase could be applied at least to a certain extent within this application case. The extent of their application, incompatibilities, and required reinterpretations are later described. Figure C.6 shows the flowchart of the phase B of the ECSS. Rectangle boxes indicate processes, while rounded boxes with dashed lines indicate milestones (e.g. reviews). Processes that are in parallel or in series can (and ideally, should) involve iterations between them.

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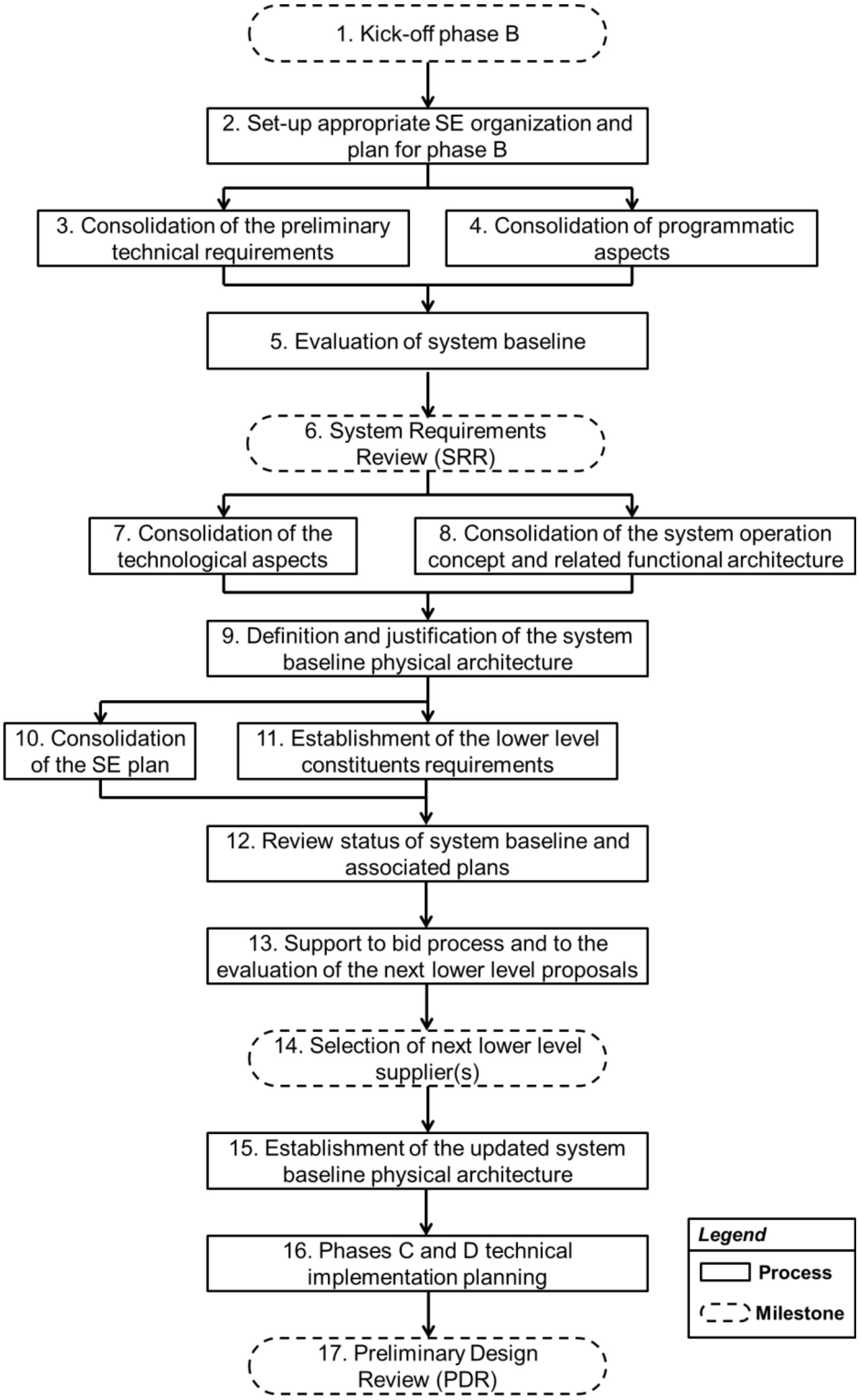
[5] The finalization of the management plan and the product assurance plan are also among the objectives of this phase. However, they are outside of the scope of this work.

Figure C.6 - Phase B of the ECSS systems engineering methodology.



Source: Adapted from ECSS (2004).

Following subsections describe the objectives and the applicable activities for each applicable process and milestone within this phase.

C.3.2.1 Kick-off phase B

The primary objectives of this milestone as well as its activities and their application on the ARD-SM would be similar to the ones described previously in section ‘C.1.2.1 Kick-off phase 0’.

C.3.2.2 Set-up appropriate SE organization and plan for phase B

The objective of this process as well as its activities and their application on the ARD-SM are similar to the ones described previously in section ‘C.1.2.2 Set-up appropriate SE organization and plan for phase 0’. However, the systems engineering plan herein refined would focus on the current phase instead. Consequently, for the ARD-SM, the systems engineering group might have determined that it would follow the flowchart as described by the ECSS standards (Figure C.6).

C.3.2.3 Consolidation of the preliminary technical requirements

The objective of this process as well as its activities and their application on the ARD-SM would be similar to the ones described previously in section ‘C.2.2.3 Consolidation of technical requirements’. In fact, the only difference between the current process activities and the activities of the process performed in phase A is that within the current process the agreement on the preliminary technical requirements should be obtained by the management group instead of both the customer organization and the management group. However, the ECSS standard states that it is a good practice to consult the customer organization within this process to avoid any misunderstanding. This process might result into the identification of new functions. For the ARD-SM, this task might have resulted in the allocation of a newly identified function for simulating maneuvers to the ground control center.

C.3.2.4 Consolidation of programmatic aspects

The objective of this process as well as its activities and their application on the ARD-SM would be similar to the ones described previously in section 'C.2.2.4 Consolidation of programmatic aspects'.

C.3.2.5 Evaluation of system baseline

This process consists in evaluating the performance of the system on the basis of all updates and clarifications provided by the customer organization and the management group.

Specifically, this process should include the following tasks:

a. Review the preliminary system baseline definition to ensure that it conforms to all technical requirements;
b. Allocate technical requirements to the different elements of the functions breakdown taking into account the physical elements previously identified;
c. Identify critical items of the lower level elements;
d. Assess the feasibility of the lower level elements;
e. Activate engineering disciplines, production, and operations groups to produce analyses that support the system performance evaluation;
f. Prepare the system verification.

It should be highlighted that the tasks of this process, specifically tasks b. to d., according to author's criteria would be more appropriate for the development of new individual systems. In the context of this work, the allocation of requirements was previously performed. Additionally, the critical items and the feasibility of lower level elements would only make sense for the ground segment systems that are within the development effort. Consequently, this process is somewhat incompatible so it cannot be applied without an interpretation and a reduction of the number of tasks by the systems engineering group. The following paragraphs show an author's interpretation of how this process and its tasks might be applicable within the scope of this work.

For the ARD-SM, task a. would consist on reviewing that the system baseline established in the previous phase meets the consolidated technical requirements.

As explained before, tasks c. and d would only occur at levels below the segment systems-level, specifically when such segment systems are within the scope of development of the engineering organization. Then, for the ARD-SM, these tasks may be only applicable by the group responsible for the development of the systems of the ground control segment (i.e. ground station and ground control center). Consequently, these tasks would be outside of the focus of the scope of this work.

Task e. for the ARD-SM might consist in the DETER system staff simulating the use of images according to the expected payload characteristics to identify how well deforestation would be detected.

Task f. might consist in producing or refining the verification plan that will be used to ensure that all the elements of the space system can actually perform as intended after the production of the elements. This verification plan might be contained by the systems engineering plan.

C.3.2.6 System Requirements Review (SRR)

The primary objectives of this milestone are:

a. Assess the updated technical requirements, the preliminary design definition, and the preliminary verification program;
b. Identify problems and questions;
c. Recommend actions or solutions;
d. Implement actions;
e. Release the updated technical requirements.

For the ARD-SM, this milestone might consist in a review made by an experienced group of specialists. It is assumed that they provide some recommendations that are accepted by the organizations and groups participating in the project, and thus, the outcomes of this phase are updated.

C.3.2.7 Consolidation of the technological aspects

This process consists in consolidating the technology aspects and establishing a list of selected technology.

Specifically, this process should include the following tasks:

a. Characterize the capabilities of the different critical technologies regarding technical requirements;
b. Determine the status of the critical technologies;
c. Perform the verifications to demonstrate the capabilities of the critical technologies by using appropriate model breadboards (digital, hardware, and software);
d. Perform sensitivity analysis to establish design margins;
e. Assess critical technologies (including process aspects);
f. Identify the risk associated with the introduction of new or advanced technologies to meet technical requirements;
g. Identify alternative lower-risk technologies that can replace higher risk technologies that are identified and assessed as unacceptable;
h. Identify the change in technical requirements for implementation of a certain technology;
i. Select technologies, COTS, end-products in accordance with the technical requirements, the risk, the cost, and the ‘make or buy’ policy.

It should be highlighted that this process and its tasks according to author’s criteria would be more appropriate for the development of new individual systems. The characterization of critical technologies, status, assessment, identification of alternative lower-risk technologies, selection, and other tasks related to this process can be appropriate for the development of subsystems or equipment. In the context of this work, this process is incompatible with the use of turnkey satellites. At maximum, this process might be applicable for the ground segments that are within the development effort at subsystem- or equipment-levels. However, within such case and in accordance with the premises of the space projects within the scope of this work, this process might be implemented by the responsible of the development of the ground segment systems and not by the systems engineering group.

C.3.2.8 Consolidation of the system operation concept and related functional architecture

This process consists in refining the operational concepts for the system and updating the related system baseline functional architecture accordingly.

Specifically, this process should include the following tasks:

a. Characterize the operations scenario including timeline definition;
b. Refine the operational concept and related operational technical requirements (e.g. all hierarchical modes and transitions, FDIR concepts, and autonomy concept);
c. Establish a detailed timeline for critical operations;
d. Incorporate the operational technical requirement in the functional architecture;
e. Validate the system design baseline according to the consolidated preliminary technical requirements to ensure the adequacy of the operational concept and the internal functional coherency.

For the ARD-SM, task a. might define the sequence and the projected time that the elements in the space system would take to detect a deforestation action in compliancy with the required response time. The timeline might look as Figure 4.4 shows.

Task b. for the ARD-SM might have resulted in the definition of two operational modes. In the first mode with the satellite pointing its payload to nadir, the payload camera would be powered on when the satellite is over the Brazilian Legal Amazon rainforest. This might be the nominal operation mode. In the second mode, the satellite might be programmed via telecommand to point its payload to specific areas of the Amazon rainforest, which would be indicated by the Ministry of the Environment during the mission.

An outcome of the task c. for the ARD-SM, specifically for the critical operation of 'processing images' might look as Table C.3 shows.

Table C.3 - ARD-SM 'processing images' critical operation.

Critical operation	Sub-operations	Maximum time required
Processing images	Transformation of image data from level-0 to level-1A	12 hour
	Level-1A image analysis	96 hours
	Detected deforestation confirmation	12 hours

Source: Author production.

Task d. for the ARD-SM might add operational requirements that were not previously defined. Such requirements might affect both the satellite and the ground control segment technical requirements and architecture. Then, task e. would consist on validating that the new requirements are in accordance with the system design baseline previously defined.

C.3.2.9 Definition and justification of the system baseline physical architecture

This process consists in defining the system baseline physical architecture (an implementation solution of the functional architecture).

Specifically, this process should include the following tasks:

a. Define the baseline system physical architecture;

b. Perform value analysis;
c. Justify the baseline system physical architecture.

It should be highlighted that this process and its tasks according to author's criteria would be more appropriate for the development of new individual systems. The definition of a physical architecture would be more appropriate in such cases in which the system is to be developed so the internal elements and relationship among them should be specified. This makes sense at segment systems-level where the subsystems and the relationship among them is essential to be defined. Similarly, at subsystems- and equipment-levels where the lower level elements and the relationship among them is essential to be defined. In the context of this work, this process is incompatible with the use of turnkey satellites. At maximum, this process might be applicable for the ground segments that are within the development effort. However, within such case and in accordance with the premises of the space projects within the scope of this work, this process might be implemented by the responsible of the development of the ground segment systems and not by the systems engineering group.

C.3.2.10 Consolidation of the SE plan

This process consists in ensuring that the design, development and verification plans are consolidated.

Specifically, this process should include the following task:

a. Detail the different appropriate verification, validation, and control plans as described in the systems engineering plan (e.g. verification, system integration, safety).
b. Prepare inputs to management and product assurance disciplines as required to update their plans.

For the ARD-SM, the aforementioned tasks would consist in updating the systems engineering plan that was refined within the ‘C.3.2.2 Set-up appropriate SE organization and plan for phase B’ process.

C.3.2.11 Establishment of the lower level constituents requirements

This process consists in establishing the technical requirements for next lower levels.

Specifically, this process should include the following task:

a. Confirm the partitioning of the system architecture;
b. Establish traceability with respect to higher level technical requirements;
c. Analyze all constraints (e.g. operational, production, and cleanliness);
d. Establish the technical requirements for the next lower level constituents (with the complete functional requirements).

It should be highlighted that this process and its tasks according to author’s criteria would be more appropriate for the development of new individual systems. The establishment of lower level constituents requirements makes sense for the development of subsystems or equipment. In the context of this work, this process is incompatible with the use of turnkey satellites. At maximum, this process might be applicable for the ground segments that are within the development effort. However, within such case and in accordance with the premises of the space projects within the scope of this work, this process might be implemented by the responsible for the development of the ground segment systems and not by the systems engineering group.

C.3.2.12 Review status of system baseline and associated plans

This process consists in confirming the maturity, consistency, and completeness of the baseline design and of the various plans associated with its development.

Specifically, this process should include the following task:

a. Confirm that the status of the system architecture is acceptable and that the requirements allocation is complete;
b. Determine that the system can fulfill the technical requirements and can be built;
c. Ensure that adequate detailed information exists (e.g. technical requirements and plans) to enable the involvement and procurement of the next lower level.

It should be highlighted that this process and its tasks according to author's criteria would be more appropriate for the development of new individual systems. As stated previously, the establishment of a physical architecture would be more appropriate in such cases in which the system is to be developed so the internal elements and relationship among them should be specified. Consequently, the confirmation of such architecture that is recommended in this process, specifically in task a., would make more sense at segment systems-level or lower levels. Furthermore, the detailed information that task c. refers to is somewhat incompatible since there have not been any contact with any manufacturer. Therefore, it is likely that no detailed information about the satellite exists at this point. Then, this process is incompatible with the use of turnkey satellites. At maximum, this process might be applicable for the ground segments that are within the development effort. However, within such case and in accordance with the premises of the space projects within the scope of this work, this process might be implemented by the responsible for the development of the ground segment systems and not by the systems engineering group.

For the ARD-SM, it is assumed that these tasks confirmed the architectures, the feasibility, and the completeness of the technical requirements of the systems of the ground control segment (e.g. the ground station and the ground control center).

C.3.2.13 Support to bid process and to the evaluation of the next lower level proposals

This process consists in supporting the bid process and contributing to the technical evaluation of the next lower level.

Specifically, this process should include the following task:

a. Deliver technical input for the next lower level project requirements documents;
b. Analyze and evaluate the technical proposals, providing technical rating to management.

It should be highlighted that this process and its tasks according to author's criteria would be more appropriate for the development of new individual systems. The establishment of bid documents for the procurement of lower level elements makes sense for the development of subsystems or equipment. In the context of this work, this process is incompatible with the use of turnkey satellites. At maximum, this process might be applicable for the ground segments that are within the development effort. However, within such case and in accordance with the premises of the space projects within the scope of this work, this process might be implemented by the responsible for the development of the ground segment systems and not by the systems engineering group. Consequently, in the context of this work, this process is somewhat incompatible so it cannot be applied without an interpretation by the systems engineering group. The following paragraphs show an author's interpretation of how this process and its tasks might be reinterpreted for its use within the scope of this work. Within this reinterpretation, the bid documents and the technical proposals can be implemented at a segment system-level for obtaining information about turnkey satellites on the market.

Another issue that should be highlighted is that according to ECSS-M-ST-10C Rev.1 standard, the project requirements documents that result from task a.

might be an integral part of an Invitation To Tender (ITT), a Request For Proposal (RFP), or a Request For Quotation (RFQ). According to author's criteria, in the ARD-SM context and especially for the satellite, an RFP would be the appropriate document among those three to be prepared within this process since the technical requirements were previously assumed as complete.

It will be assumed that for the satellite of the ARD-SM, three different manufacturers submitted proposals. Figure 4.7, Figure 4.8, and Figure 4.9 show a brief summary of some of the characteristics of each of the alternatives.

Then, task b. would consist in evaluating the satellite proposals and provide technical rating to the management group. For the ARD-SM, it will be assumed that after analysis of how well the proposals fulfilled the technical requirements, the proposal #1 was recommended. Then, the second proposal was recommended as second option, and finally, the third proposal as third option.

It will be assumed that for the ground control segment of the ARD-SM this process was not performed since such segment will be developed. If the procurement of lower level elements of such segment is required, this process might be performed by the group responsible for such development. However, this would be outside of the focus of this work.

C.3.2.14 Selection of next lower level supplier(s)

The primary objective of this milestone is:

a. Select the next lower level suppliers.

It should be highlighted that this process and its tasks according to author's criteria would be more appropriate for the development of new individual systems. The selection of a supplier makes more sense when similar proposals are received so the selection could be reduced to supplier aspects, such as its experience, previous results, or the price of the proposal. In the context of this work, this process is incompatible with the use of turnkey satellites for two reasons. First, the proposals received in the last process (without the proposed reinterpretation) would only make sense for the procurement of subsystems and equipment. Second, the proposals received in the last process (with the proposed reinterpretation) are likely to be different so the selection should not be reduced only to the suppliers but also should consider technical differences among the alternatives. This process without modifications, at maximum, might be applicable for the ground segments that are within the development effort. However, within such case and in accordance with the premises of the space projects within the scope of this work, this process might be implemented by the responsible for the development of the ground segment systems and not by the systems engineering group. In similarity with previous process, this process cannot be applied without an interpretation by the systems engineering group. The following paragraphs show an author's interpretation of how this process and its tasks might be reinterpreted for its use within the scope of this work. Within this reinterpretation, which is similar to the reinterpretation proposed for the previous process, the suppliers selection can be implemented at a segment system-level for selecting among the proposed turnkey satellites.

For the ARD-SM, this milestone might consist in a meeting with participation of all the organizations and groups involved in the project. It will be assumed that Yuzhnoye was chosen as the supplier of the satellite accordingly to the recommendations made by the systems engineering group.

C.3.2.15 Establishment of the updated system baseline physical architecture

This process consists in consolidating the system baseline according to the selected suppliers.

Specifically, this process should include the following task:

a. Evaluate the need to update lower level input with respect to compliancy with system level assumptions and updates;

b. Initiate system level analyses updates;
c. Evaluate updates on the analyses and their consequences on design, interfaces, and performances at all levels;
d. Update major changes to operational and physical architecture, including harmonization with other mission elements (e.g. ground segment);
e. Consolidate and optimize architectures in view of previous results;
f. Agree on the technical requirements for the next lower level elements.

As stated previously the physical architecture would be more appropriate in such cases in which the system is to be developed so the internal elements and relationship among them should be specified. This makes sense at segment systems-level where the subsystems and the relationship among them is essential to be defined. Similarly, at subsystems- or equipment-levels lower level elements and the relationship among them is essential to be defined. In the context of this work, this process is incompatible with the use of turnkey satellites. At maximum, this process might be applicable for the ground segments that are within the development effort. However, within such case and in accordance with the premises of the space projects within the scope of this work, this process might be implemented by the responsible of the development of the ground segment systems and not by the systems engineering group. The following paragraphs show an author’s interpretation of how this process and its tasks might be reinterpreted for its use within the scope of this work.

For the ARD-SM, task a. would consist in assessing how the selected satellite will affect the requirements of the ground segments and their systems (e.g. the ground station and the control center of the ground control segment).

Task b. might include updating the orbital analysis to see for instance, how the chosen satellite characteristics will increase or reduce the revisit time or the access time with the ground application segment. It might also include an update of the links analysis, which might result into a change for example in the ground station receptor sensibility (task c.). As stated previously, tasks d., e., and f. might be implemented by the responsible of the development of ground segment systems and might result into a detailed update of ground control segment systems architectures and definition for consolidate and optimize the design.

C.3.2.16 Phases C and D technical implementation planning

This process consists in establishing the technical planning for the agreed baseline for the phases C-D.

Specifically, this process should include the following task:

a. Confirm the design, development, and verification approach;
b. Refine the systems engineering plan and all associated plans for next phases.

For the ARD-SM, tasks a. and c. would consist in confirming and updating the systems engineering plan that was refined within the 'C.3.2.10 Consolidation of the SE plan' process. Some of the following phases plans might be responsibility of the selected satellite manufacturer or of the group responsible for the development of the ground segment systems.

C.3.2.17 Preliminary Design Review (PDR)

The primary objectives of this milestone are:

a. Verify the preliminary design of the selected concept and technical solutions against project and system requirements;
b. Assess the product and work decompositions and the final plans;
c. Identify problems and questions;
d. Recommend actions or solutions;
e. Implement actions;
f. Release the product and work decompositions and the final plans.

Some of the requirements, product decompositions, work decompositions, and final plans herein referred might be responsibility of the selected satellite manufacturer or of the engineering disciplines groups responsible for the development of the ground segment systems.

For the ARD-SM, this milestone might consist in a review made by an experienced group of specialists. It is assumed that they provide some recommendations that are accepted by the organizations and groups participating in the project, and thus, the outcomes of this phase are updated.

C.4 **Phase C: detailed definition**

C.4.1 Phase C objectives

The main objective of this phase is to establish the detailed definition of the system that will satisfy the technical requirements and demonstrate its capability to meet such requirements.

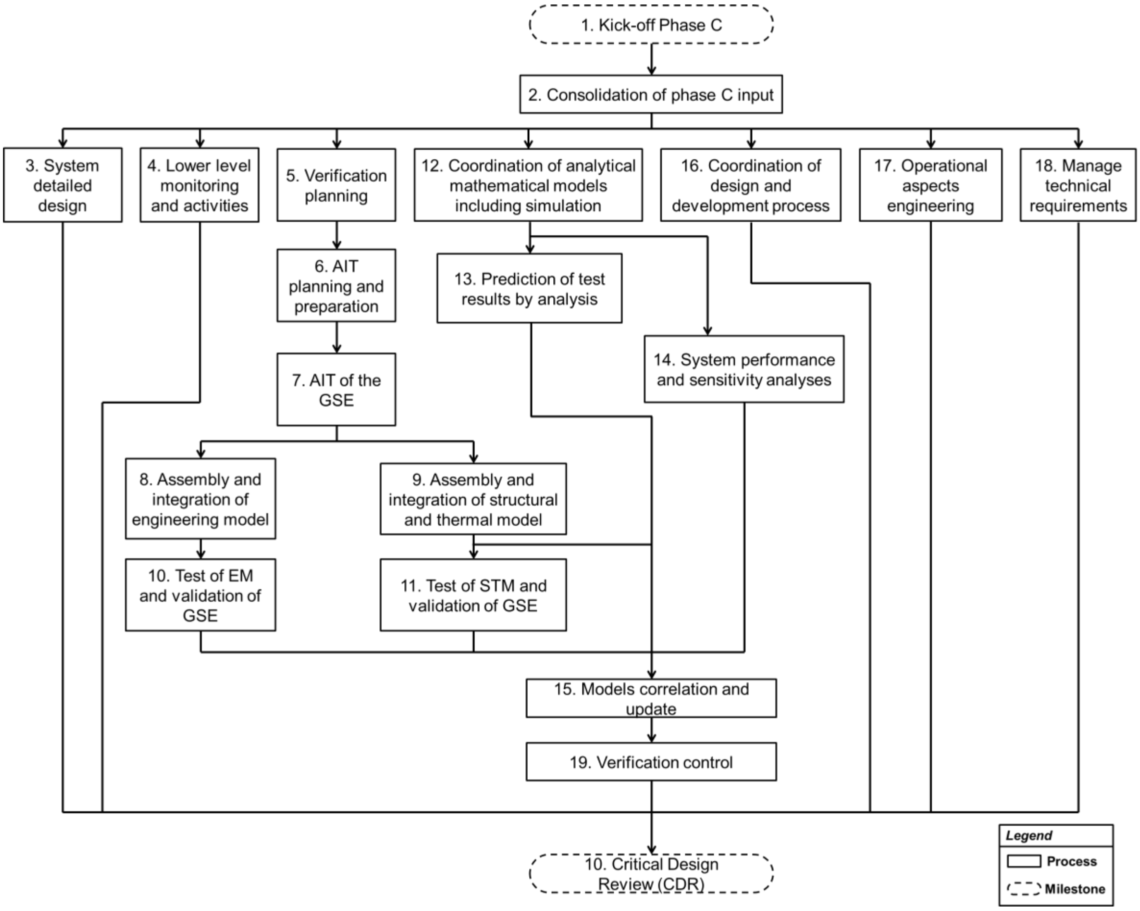
The specific objectives of this phase within the systems engineering effort are:

- Completion of the detailed design definition of the system at all levels;
- Completion of assembly, integration, and test planning for the system and its constituent parts;
- Detailed definition of internal and external interfaces.

C.4.2 Phase C processes and milestones

The author analyzed the objective of each of the processes and milestones within this phase to identify if any of them would not be appropriate within the scope of this work and the particular application case. Figure C.7 shows all the processes and milestones of the phase C according to the ECSS. Rectangle boxes indicate processes, while rounded boxes with dashed lines indicate milestones (e.g. reviews). Processes that are in parallel or in series can (and ideally, should) involve iterations between them.

Figure C.7 - Phase C of the ECSS systems engineering methodology.



Source: Adapted from (ECSS, 2004).

After the analysis, the author determined that the following processes would not be appropriate for their application in the application case:

- '3. Detailed design': this process consists in consolidating the baseline physical architecture of the system and ensuring the completion of its detailed design. The activities within this process only makes sense at low levels such as subsystem- and equipment-levels. Consequently, they will be performed by the engineering disciplines groups for the ground segments within the development effort or by the manufacturers of the selected turnkey satellite and the ground segments that should be procured. For such reason, the activities associated to this process are outside of the scope of this work;

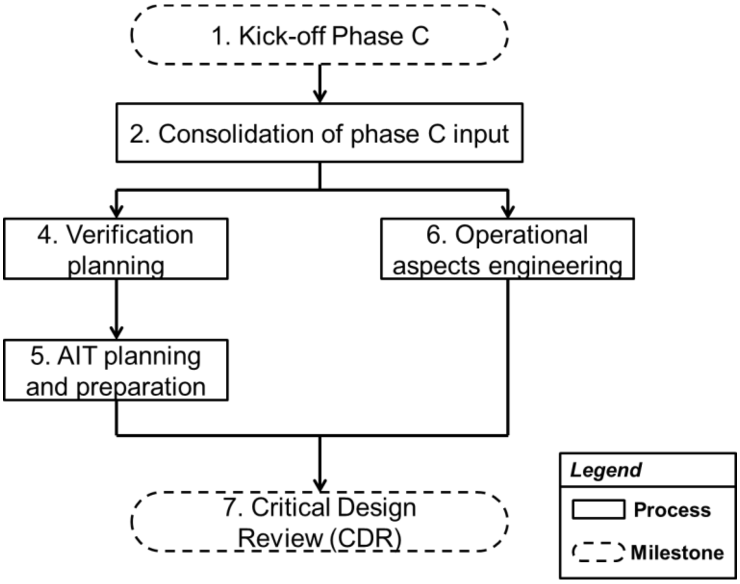
- ‘4. Lower level monitoring and activities’: this process consists in monitoring the engineering activities of the lower levels. Monitoring activities are outside of the scope of this work;
- ‘7. AIT of the GSE’: this process consists in production activities of the support equipment for the space system. Production activities are outside of the scope of this work;
- ‘8. Assembly and integration of engineering model’: this process consists in production activities of the satellite, which should be performed by satellite manufacturers. Furthermore, the engineering model is likely to not be developed when procuring turnkey satellites, especially if the turnkey satellite has flight experience or high heritage from previous versions. For both reasons, this process is outside of the scope of this work;
- ‘9. Assembly and integration of structural and thermal model’: this process consists in production activities of the satellite, which should be performed by satellite manufacturers. Furthermore, the structural and thermal model is likely to not be developed when procuring turnkey satellites, especially if the turnkey satellite has flight experience or high heritage from previous versions. For both reasons, this process is outside of the scope of this work;
- ‘10. Test of EM and validation of GSE’: this process would be outside of the scope of this work for the same reasons given for the exclusion of process ‘8. Assembly and integration of engineering model’;
- ‘11. Test of STM and validation of GSE’: this process would be outside of the scope of this work for the same reasons given for the exclusion of process ‘9. Assembly and integration of structural and thermal model’;
- ‘12. Coordination of analytical mathematical models including simulation’: this process consists in coordinating the development and use of the engineering analytical models and the simulation models to ensure adequate coverage of all system level life cycle activities. Coordinating activities are outside the scope of this work;

- ‘13. Prediction of test results by analysis:’ this process consists in controlling the activities of the engineering disciplines groups that provide reference results for the planned tests. Controlling tasks are outside of the scope of this work;
- ‘14. System performance and sensitivity analysis:’ this process consists in controlling the activities of the engineering disciplines groups that provide predictions of functional performance and sensitivity analysis. Controlling tasks are outside of the scope of this work;
- ‘15. Models and correlation update’: this process consists in controlling the activities of the engineering disciplines groups that correlate and update the models. Controlling tasks are outside of the scope of this work;
- ‘16. Coordination of design and development process’: this process consists in controlling the systems engineering group and its outputs as well as coordinating such group with the others. Controlling and coordination activities are outside of the scope of this work;
- ‘18. Manage technical requirements’: this process consists in managing the technical requirements, which would be a control activity of the systems engineering group. Control activities are outside of the scope of this work;
- ‘19. Verification control’: this process consists in compiling evidence that all verification activities were properly performed, which would be a control activity of the systems engineering group. Control activities are outside of the scope of this work.

It should be highlighted that the aforementioned activities are either controlling activities or are activities that are supported by the systems engineering group but are the responsibility of another group. Consequently, the majority of the processes of this phase are not applicable within the scope of this work. Furthermore, as is shown in subsequent paragraphs, some of the process that were considered to be applicable still refer to lower level elements. Consequently, such processes are somewhat incompatible and require a reinterpretation as it is shown next.

Figure C.8 illustrates how the flowchart of the phase C of the ECSS methodology might look with the considerations previously described. Rectangle boxes indicate processes, while rounded boxes with dashed lines indicate milestones (e.g. reviews). Processes that are in parallel or in series can (and ideally, should) involve iterations between them.

Figure C.8 - Adjusted phase C of the ECSS systems engineering methodology.



Source: Adapted from (ECSS, 2004).

Following subsections describe the objectives and the applicable activities for each applicable process and milestone within this phase.

C.4.2.1 Kick-off phase C

The primary objectives of this milestone as well as its activities and their application on the ARD-SM would be similar to the ones described previously in section ‘C.1.2.1 Kick-off phase 0’.

C.4.2.2 Consolidation of phase C input

This process consists in consolidating the phase C inputs and contributing to their implementation.

Specifically, this process should include the following tasks:

a. Review the programmatic aspects and constraints in order to confirm, clarify, or extend them;
b. Consolidate the system and next lower level elements technical requirements;
c. Update the systems engineering plan and related plans.

The application of similar tasks within the ARD-SM was already exemplified in previous processes.

C.4.2.3 Verification planning

This process consists in refining the verification approach to an adequate level of detail for execution of phase C and preparation of phase D.

Specifically, this process should include the following tasks:

a. Confirm and refine the verification strategy;
b. Produce the system test requirements;
c. Assess the adequacy of next lower level test requirements;
d. Establish the detailed planning of verification activities in terms of schedule, resources, and cost.

It should be highlighted that this process is somewhat incompatible within the scope of this work. Some of the tasks of this process that refers to lower levels would be more appropriate for the development of new individual systems. Within the scope of this work, as stated previously, activities related to lower levels than the segment systems would only make sense for the ground segment and even in such cases, they would outside the responsibility of the systems engineering group. However, the following paragraph shows an author’s interpretation of how this process might be applied within the scope of this work.

For the ARD-SM, this process might be applied at segment system-level for producing results such as: plan for verification activities for the satellite, test requirements for ensuring that the satellite will be compatible with the ground application segment, and test requirements of the ground station of the ground control segment.

C.4.2.4 AIT planning and preparation

This process consists in detailing the system AIT plan.

Specifically, this process should include the following tasks:

a. Establish the system AIT plan;
b. Support and approve integration and test procedures;
c. Establish the GSE specifications;

It should be highlighted that this process is somewhat incompatible within the scope of this work. The AIT plan of the satellite, including its integration and test procedures should be responsibility of the turnkey satellite manufacturer. Similarly, for the ground segment systems within the development effort, this process would be outside of the responsibility of the systems engineering group. However, the following paragraph shows an author's interpretation of how this process might be applied within the scope of this work.

For the ARD-SM, this process might consider the integration and test among several segment systems. Consequently, this process might produce results such as the plan for upcoming test activities among the turnkey satellite and the ground application segment, integration procedure between the ground control center and its ground station, and the specifications of the RF suitcase to test the compatibility between the turnkey satellite and the ground stations.

C.4.2.5 Operational aspects engineering

This process consists in ensuring that the system design conforms to the operational requirements.

Specifically, this process should include the following tasks:

a. Consolidate the operations scenario including installation, launch, flight, operations, and related timeline;
b. Confirm the compatibility between the operational technical requirements and the operations scenario;
c. Establish the preliminary pre-launch, launch, and flight operations procedures.

It should be highlighted that the installation and launch scenarios as well as the pre-launch and launch procedures should be responsibility of the turnkey satellite manufacturer or of the launch service provider contracted by the satellite manufacturer. In any of both cases, it is not responsibility of the systems engineering group. Similarly, flight operations procedures (e.g. camera calibration, maneuvers, transition between operational modes) should be responsibility of the operations group or an engineering disciplines group. Consequently, this process is somewhat incompatible so it cannot be applied without an interpretation and a reduction of the number of tasks by the systems engineering group. The following paragraphs show an author’s interpretation of how this process and its tasks might be applicable within the scope of this work.

For the ARD-SM, task a. might detail and consolidate the timelines that were established during the previous phase for flight or mission operations (e.g. imaging, maneuvers, attitude operations, calibration) with the support of operations or engineering disciplines groups. Then, task b. might confirm that all the operational requirements will be met by the space system.

C.4.2.6 Critical Design Review (CDR)

The primary objectives of this milestone are:

a. Assess the final design; the assembly, integration, and test planning;
b. Confirm compatibility with external interfaces;
c. Identify problems and questions;
d. Recommend actions or solutions;
e. Implement actions;
f. Release the final design; the assembly, integration, and test planning.

The final design as well as the assembly, integration, and tests plans herein referred typically refers to segment systems, such a satellite. However, this milestone might be reinterpreted in order to be applied at the space system–level and consequently, be applicable within the scope of this work.

For the ARD-SM, this milestone might consist in a review made by an experienced group of specialists. It is assumed that they provide some recommendations that are accepted by the organizations and groups participating in the project, and thus, the outcomes of this phase are updated.

ATTACHMENT D - SYSTEMS ENGINEERING FUNDAMENTALS

This attachment describes essential concepts of the systems engineering effort.

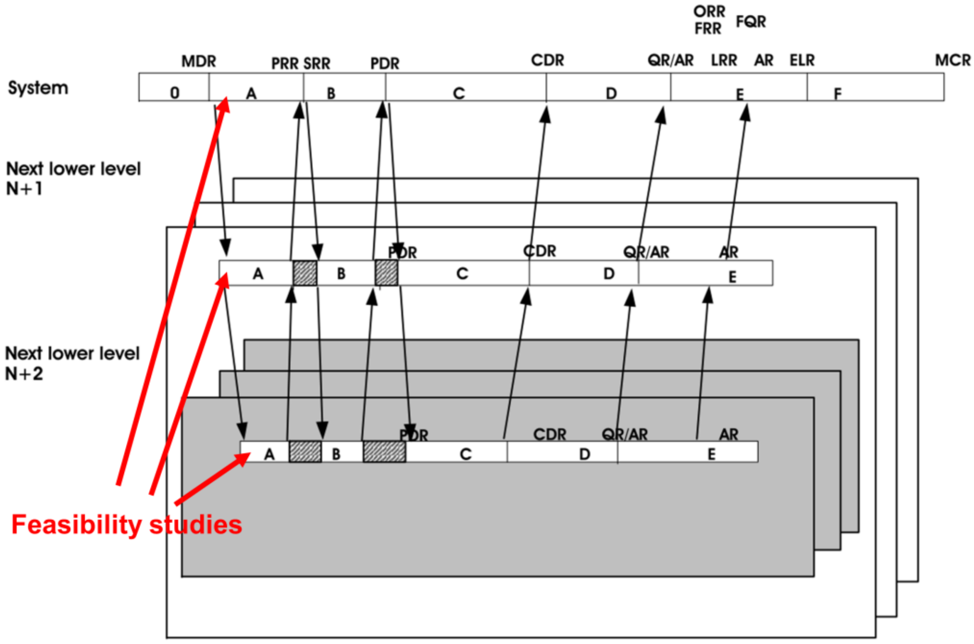
ISO et al. (2015a, p.10) define systems engineering as the

> Interdisciplinary approach governing the total technical and managerial effort required to transform a set of stakeholder needs, expectations, and constraints into a solution and to support that solution throughout its life. (ISO et al., 2015a, p.10)

The systems engineering effort flows down requirements to the highest hierarchical level of the system up to the lowest level within the scope of the development. The lowest level would depend on project considerations.

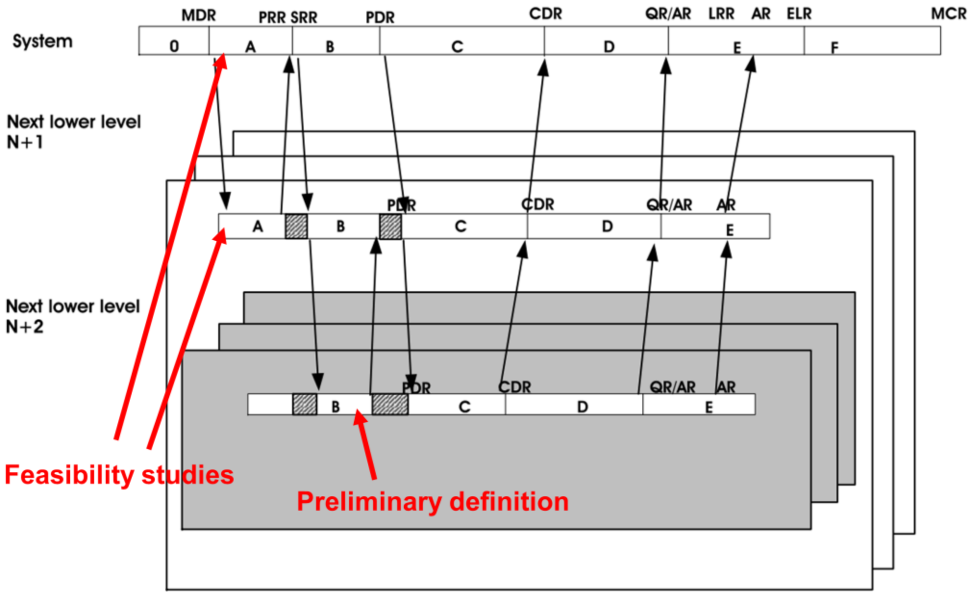
ECSS (2004) shows that project considerations do not affect only the hierarchical decomposition but also the performing or not of some activities at different hierarchical levels during different phases. For instance, systems engineering efforts for developing systems that incorporate new technologies at their lowest level should perform feasibility studies at all its levels. On the other hand, systems engineering efforts in which no new technology is being incorporated at the lowest level would skip feasibility studies for such level and begin with its preliminary definition. Furthermore, systems engineering efforts in which the lowest level will be implemented through recurring products would not need feasibility and definition activities, and thus, it may go directly to the utilization of such products when appropriate. These three examples are illustrated in Figure D.1, Figure D.2, and Figure D.3, respectively.

Figure D.1 - Systems engineering effort with new technology.



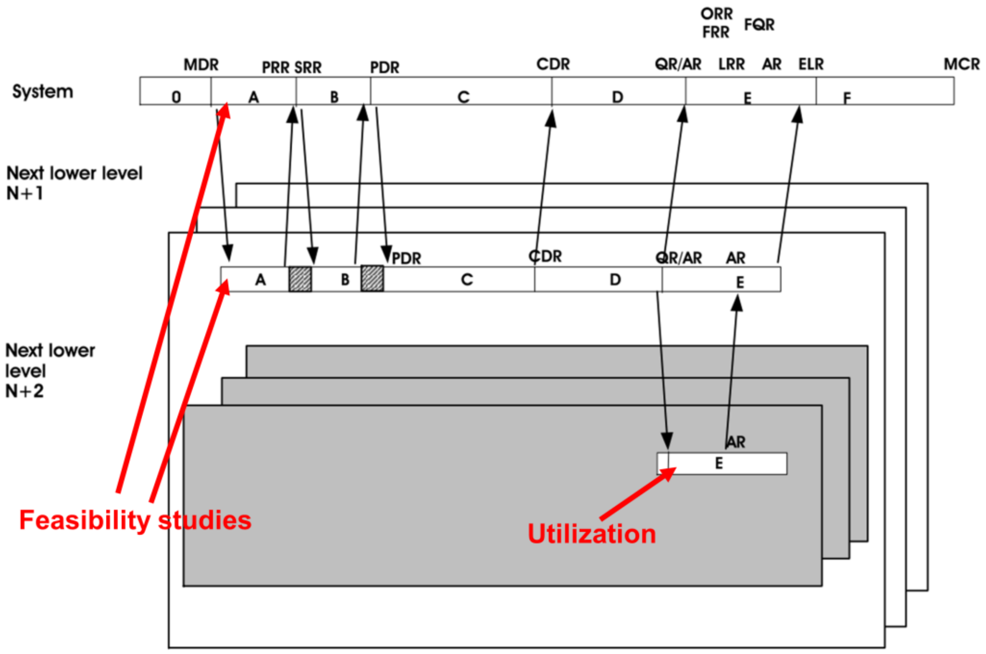
Source: Adapted from ECSS (2004).

Figure D.2 - Systems engineering effort with no new technology.



Source: Adapted from ECSS (2004).

Figure D.3 - Systems engineering effort with a recurring product.



Source: Adapted from ECSS (2004).

The aforementioned top-down approach is known as the need-driven process. Another approach for space systems engineering is the capability-driven approach. While the need-driven approach begins with a set of needs that defines the mission and the system, the capability-driven approach begins with the identification of a new capability or a new way to employ an existing capability. Then, the effort focuses on finding a space mission that could use that capability. Subsequent processes within this approach are similar to the ones previously described. By employing existing capabilities, a system could be delivered faster and at a lower cost. An example of capabilities-based systems is the Global Positioning System (GPS) occultation system, which is composed by Low-Earth Orbit (LEO) satellites that use the existing GPS satellites (the existing capability) for measuring some ionospheric and atmospheric characteristics. Space systems must be engineered by balancing the need-driven and the capability-driven approaches, i.e. balancing the needs with the capabilities. (WERTZ et al., 2011)

Hall (1969) describes that systems engineering effort can be regarded as a methodology when two fundamental dimensions are defined: a temporal dimension and a logical dimension.

The temporal dimension of systems engineering represents the evolution of a system, product, service, project or other human-made entity from conception to retirement (i.e. the lifecycle). The temporal dimension, or lifecycle, is composed by phases (or stages[6]) through which the system, product, service, project or other human-made entity passes. (HALL, 1969; INCOSE, 2015; ISO et al., 2015a)

The logical dimension of systems engineering represents the problem solving processes that must be performed in order to solve a problem. These processes are composed of activities that allow the system to progress through its lifecycle. The processes may be repeated in successive phases and performed in any order, but each of them must be performed to solve the problem. (HALL, 1969; ISO et al., 2015a)

The following subsections provide more details about the systems engineering effort. Specifically, they provide details about the systems engineering phases, processes, and information items.

D.1 **Systems engineering phases**

This section describes general systems engineering phases that are used by different organizations to represent the evolution of a system, product, service, project or other human-made entity through its lifecycle.

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[6] The terms phase and stage are herein considered as equivalent as some references do. However, other references make a distinction between both terms referring to stage as the different states of a system during its lifecycle and to phases as the different steps of the program that support and manage the life of the system (BKCASE, 2016).

The phases represent the major periods associated with the system and its state, and they are separated by major decision milestones (e.g. reviews) (HALL, 1969; ISO et al., 2015).

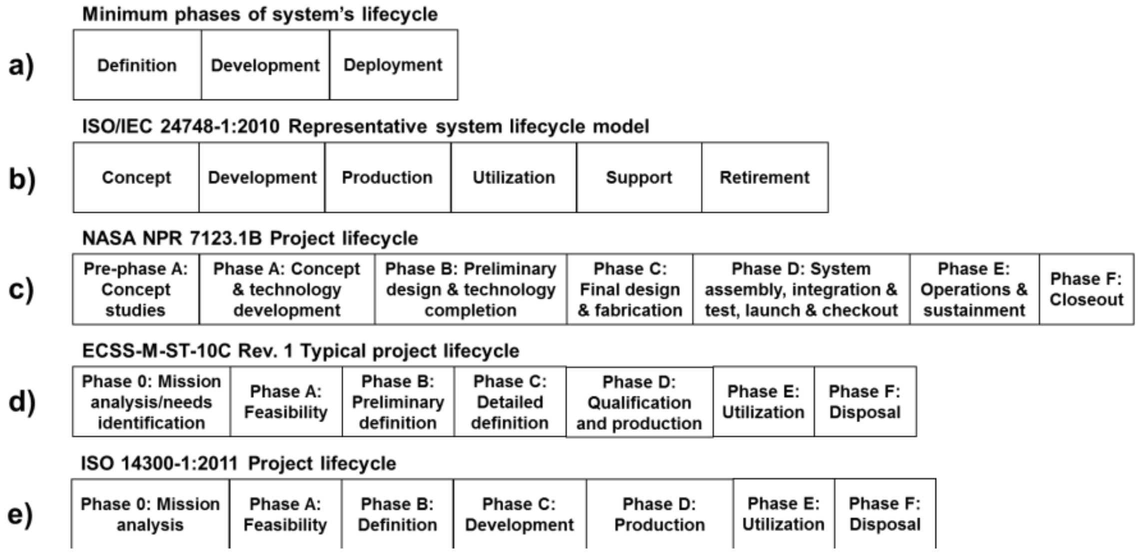
Milestones, according to the Project Management Institute (PMI) (2008), are significant points or events in the project. Furthermore, NASA (2007) adds that at milestones decision authorities determine the readiness of a program or project to progress to the next milestone or phase. NASA (2007) states that milestones can also be referred as 'key decision points'.

According to Sage and Armstrong Jr. (2000), a system lifecycle is composed at least by the following three phases:

- Definition – It consists in establishing what the system requires to do or have;
- Development – It consists in producing the system;
- Deployment – It consists in using the system in its operational environment.

As AcqNotes (2016) affirms, there is no one standard systems engineering approach. Consequently, as Fortescue et al. (2011) state, the definitions used in different organizations can vary. Figure D.4 illustrates the different phases that are implemented by various organizations such as NASA, ISO, and ECSS.

Figure D.4 - Lifecycle model examples.

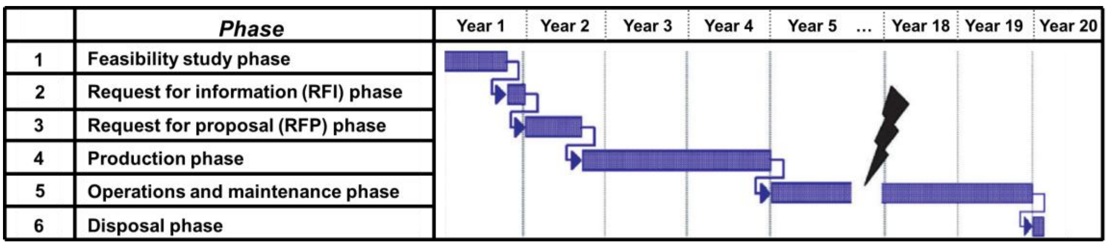


Item 'a)' shows the minimum phases that a system lifecycle must have according to Sage and Armstrong Jr. (2000). Item 'b)' shows a generic system lifecycle model according to ISO and IEC (2010). Item 'c)' shows the space project lifecycle according to NASA (2013). Item 'd)' shows the space project lifecycle according to ECSS (2009a). Finally, item 'e)' shows the space project lifecycle according to ISO (2011).

Source: Author production.

Fortescue et al. (2011) highlight that traditional phasing of space projects may be significantly shortened in the case of commercial programs, particularly if existing platforms are used. Furthermore, they add that it is usual for a commercial program to perform the contractual delivery when the spacecraft is in a fully operational state, after an in-orbit commissioning phase. Ley et al. (2009) describe that the execution of a commercial program typically consists in six phases as Figure D.5 shows.

Figure D.5 - Typical implementation phases for commercial satellite systems.



Source: Adapted from Ley et al. (2009).

D.2 **Systems engineering processes**

This section describes general systems engineering processes that are used by different organizations to solve a problem.

According to Sage and Armstrong Jr. (2000), any systems engineering effort is composed at least by three fundamental processes:

- Formulation of the problem – It consists in assessing the situation or issue; identifying the needs and associated requirements, the objectives to be satisfied, the constraints and the variables affecting the solution; and generating potential solution alternatives;
- Analysis of alternatives – It consists in identifying and assessing the impact of the identified alternatives, including possible refinement among alternatives;
- Interpretation and selection – It consists in ranking the alternatives in terms of their impact and needs satisfaction, and selecting one for implementation or further study in a subsequent phase.

Hall (1969) and Sage and Armstrong Jr. (2000) expand the three fundamental processes providing a more detailed view of systems engineering. By this view, the systems engineering effort is composed by the following processes:

- Problem definition – It consists in isolating, quantifying, and clarifying the need that creates the problem, as well as describing constraints and environmental factors limiting the variables for the system to be developed;
- Value system design – It consists in developing objectives (or goals) for guiding the search for alternatives, and a decision criterion (generally multidimensional) for guiding the selection among them;
- Systems synthesis – It consists in searching, collecting or inventing a number of potential solution alternatives;
- Systems analysis – It consists in determining the impacts (or consequences) of the alternatives on the value system;

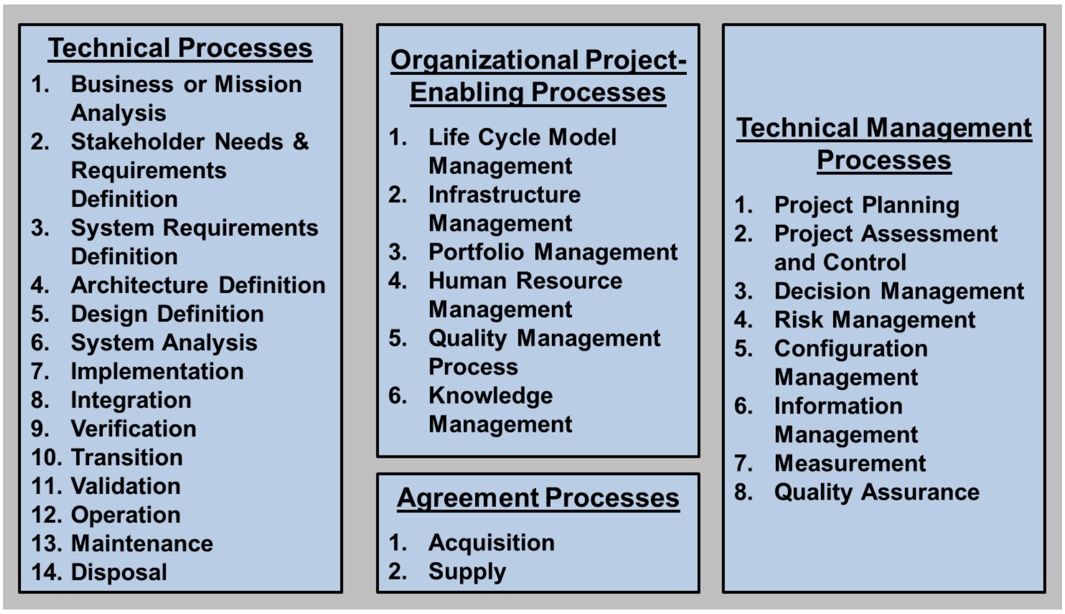
- Optimization of alternatives – It consists in adjusting the system variables of each alternative to meet, as best it can, the objectives comprising the value system, and thereby, allowing a consistent and rational choice among alternatives;
- Decision-making – It consists in evaluating, combining, and interpreting the impacts of the alternatives in terms of the rules prescribed by the value system; and subsequently, selecting one or more alternatives to advance for next processes or phases;
- Planning for action – It consists in communicating the results of systems engineering up to this point and planning for the next phase (or the implementation if current phase is the final).

ISO et al. (2015a) and INCOSE (2015) propose a more detailed expansion of the systems engineering processes that can be performed during the lifecycle of a system and group them into four groups:

- Technical processes – They represent technical activities throughout the lifecycle that transform the needs of stakeholders into a product and service;
- Agreement processes – They represent the activities necessary to establish an agreement between two organizations, one acting as customer and the other acting as a supplier;
- Technical management processes – They represent technical and administrative activities used to plan, organize and control the engineering functions (i.e. the technical processes) of a project or its products;
- Organizational project-enabling processes – They represent the activities that establish the environment in which projects are conducted, such as policies, lifecycle models and processes, resources (both human and financial), infrastructure, quality measures, as well as other activities that direct, enable, control, and support the system lifecycle.

Figure D.6 shows the processes within each of the aforementioned groups as indicated by ISO et al. (2015a) and INCOSE (2015).

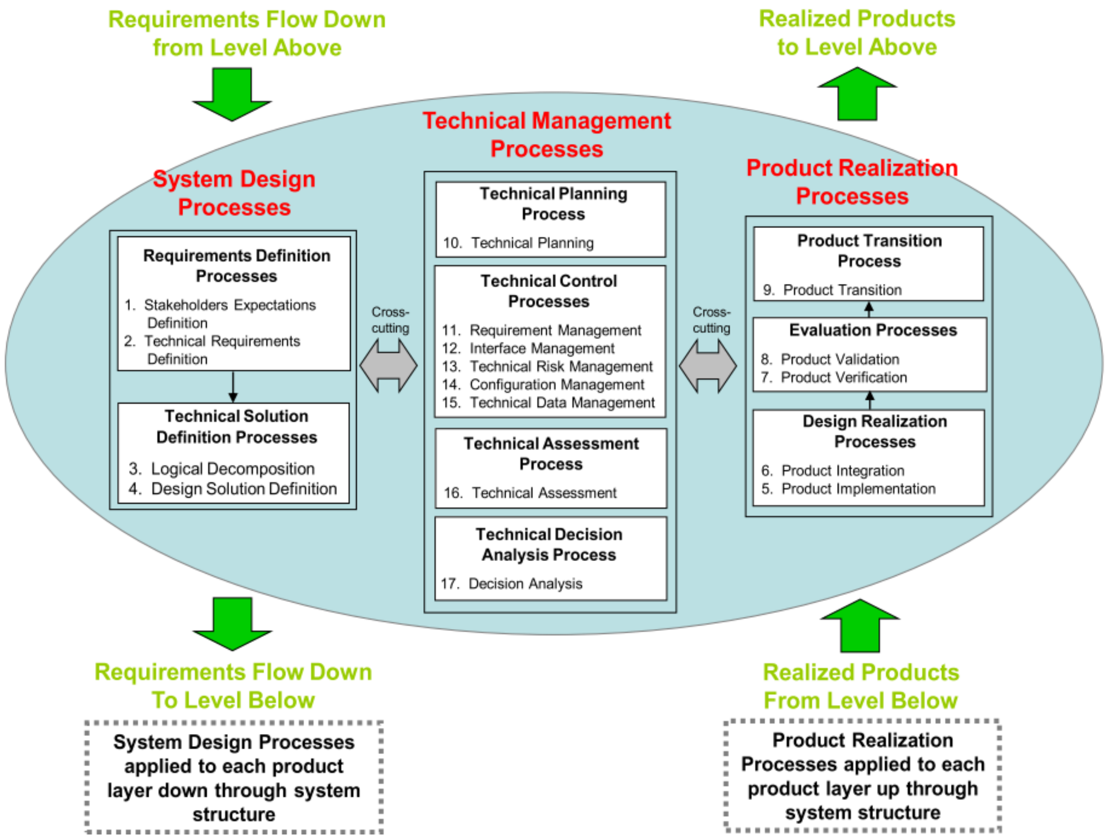
Figure D.6 - Grouping of systems engineering processes.



Source: Author production.

As AcqNotes (2016) affirms, there is no one standard definition or detailed systems engineering approach. Consequently, the systems engineering approach can change according to the organization who implements it and according to the project in which it is implemented. Figure D.7, Table D.1, and Table D.2 show some examples of space systems engineering processes according to NASA (2013), Wertz and Larson (2005), and Larson et al. (2009), respectively.

Figure D.7 - NASA systems engineering processes.



NASA processes are technical and technical management processes. The system design and the product realization processes constitute the technical processes.

Source: NASA (2013).

Table D.1 - Space mission analysis and design (SMAD) processes.

Process	Subprocesses
Define objectives	1. Define broad objectives and constraints 2. Estimate quantitative mission needs and requirements
Characterize the mission	3. Define alternative mission concepts 4. Define alternative mission architectures 5. Identify system drivers for each 6. Characterize mission concepts and architectures
Evaluate the mission	7. Identify critical requirements 8. Evaluate mission utility 9. Define mission concept (baseline)
Define requirements	10. Define system requirements 11. Allocate requirements to system elements

The SMAD processes are technical processes applied during the initial phases of a space project.

Source: Adapted from Wertz and Larson (2005).

Table D.2 - Applied space systems engineering (ASSE) processes.

Process	Subprocesses
Design the system	Define needs and stakeholders expectations Generate concept of operations and operational architecture Develop system architecture – functional and physical Determine technical requirements, constraints and assumptions Make decisions and conduct trade-off analyses Estimate lifecycle cost Assess technical risk
Realize the system	Integrate the system Implement the system Verify and validate the system Transition the system into use
Manage creation, development, and implementation of the system	Plan and manage the technical effort Develop and implement a systems engineering management plan Control interfaces Maintain configuration Manage technical data Review and assess technical effort
Document and iterate	

The ASSE processes are both technical and technical management processes.

Source: Adapted from Larson et al. (2009).

D.3 **Systems engineering information items**

This section describes some information items of the systems engineering effort, which enable the implementation of processes and the consequently evolution of the system through the phases.

According to ISO et al. (2015b), information items are separately identifiable bodies of information that are produced, stored, and delivered for human use. They describe that any document can be an information item, or part of an information item, or a combination of several information items. Furthermore, they add that an information item can be produced in several versions during a project lifecycle.

The following subsections describe relevant information items of the systems engineering effort within the scope of this work.

D.3.1 Mission statement

The mission statement states what the customer or sponsor wants. Consequently, it represents the problem or opportunity space. The mission statement serves to identify the mission objectives, which should describe the aims of the mission in qualitative and general enough terms to remain virtually unchanged during the design process. (FORTESCUE et al., 2011; LARSON et al., 2009; WERTZ; LARSON, 2005)

The mission statement should be formulated in a few sentences only containing three core statements: the motivation for the mission (rationale and initial situation), the mission idea (how the mission elements interact), and the user or user groups of the mission. It should contain self-explanatory sentences and be clearly understandable to everybody. Furthermore, it should describe needs to 'have' or 'do' something rather than a need 'for' something. However, requirements can also find their way into mission statements (LARSON et al., 2009; LEY et al., 2009; WERTZ; LARSON, 2005)

Initial customer needs may be in response to a current functional deficiency, an existing operational deficiency, a desire to leverage new technology breakthroughs to enhance mission capability or market positioning, an evolving threat or competition, or to improve the capability based on behavior of current systems and their operators or maintainers. (LARSON et al., 2009)

Although the customer understands better than anybody else the need that it is trying to satisfy, the customer cannot always express such need in clear or complete terms. Furthermore, what the customer says it wants may not solve the problem or may not solve it optimally. (HALLIGAN, 2012a)

Ley et al. (2009, p.654) exemplifies a mission statement as follows:

> Because of the increasing impact of fires on forest and savannah ecosystems and on the atmosphere and climate, the global acquisition and measurement of fire parameters in space and time is of increasing importance. A dedicated satellite system with global coverage for daily acquisition and surveying of fire data in the regions concerned supports the daily briefing of those engaged in the management of major fires and the investigation of their implications by scientists, local authorities, organizations and insurance companies. Such a spaceborne sensor system can also detect and support the remote sensing of other high-temperature phenomena like volcanic activity and can provide unique data for scientists and government administrators. (LEY et al., 2009, p.654)

D.3.2 Stakeholder needs

The Oxford Dictionary (2016) defines needs as something that is wanted or required. INCOSE (2015) adds that needs for a system are often capabilities or things that are lacking but wanted or desired by one or more stakeholders.

In addition, a stakeholder is any entity (individual or organization) with a legitimate interest in the system. Stakeholders are all those who may be affected by or able to influence the system. Typical stakeholders are the sponsors, customers, users, operators, organization decision makers, parties to the agreement, regulatory bodies, developing agencies, developers, producers, trainers, maintainers, disposers, supplier organizations, support organizations, and society at large (within the context of the problem and proposed solution). (INCOSE, 2015; ISO et al., 2010; LARSON et al., 2009)

Needs exist independent of any solution to those needs – the stakeholder has a need whether or not it can be met. A system or solution may be developed to satisfy those needs. However, the system itself is not the need; it is a response to the problem or opportunity, instead. When a customer is procuring a satellite, it is actually buying a capability, not a satellite. The satellite is simply the means to that end. Consequently, needs should describe a need to ‘have’ or ‘do’ something, not a need ‘for’ something. Otherwise, the focus becomes the solution. (LARSON et al., 2009)

A particular type of need is a constraint, which according to PMI (2008) is an applicable restriction or limitation, either internal or external to a project, which affects the performance of the project or a process. Similarly, Ley et al. (2009) define constraints a strict demands that result from economic, strategic, political, and/or physical considerations. Ley et al. (2009) provide some examples of constraints in the context of space systems, such as: a given development time for a space mission; a given operational lifetime; a fixed cost limit; a funding model; cooperation with national or international partners; the use of particular ground stations; compatibility with particular ground stations; and establishments and use of national technologies. (LEY et al., 2009)

INCOSE (2015) states that stakeholder needs are determined from communication with external and internal stakeholders in order to understand their expectations, needs, requirements, values, problems, issues, and perceived risks and opportunities. Larson et al. (2009) add that stakeholders talk in terms of features they think they need. As Halligan (2012) states, although stakeholders understand better than anybody else the needs to be addressed, they cannot always express such needs in clear or complete terms. Furthermore, he adds that what the stakeholders say they want may not solve the problem or may not solve it optimally. The MITRE Corporation (2014) adds that key attributes and metrics are frequently missing, stated in ambiguous terms, or stated with no corroborating analysis or evidence basis.

Some information gathering tools and techniques are structured interviews; cost/benefit analysis; Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis; brainstorming or white board sessions; field data and analysis; surveys; and customer feedbacks or comment cards. (LARSON et al., 2009)

Larson et al. (2009) describe that systems engineers should find out why declared needs are important and determine what the stakeholder needs truly are. Similarly, the MITRE Corporation (2014) states that assessments should be performed to understand better the stakeholders needs, and consequently, to determine the best capabilities that will help stakeholders address their needs. LEY et al. (2009) add that a detailed analysis of needs can lead to the modification of the mission objectives, and then, the mission requirements can be derived. However, as the MITRE Corporation (2014) affirms, it is a challenge to extract the full definition of the underlying capability needed; obtain stakeholder consensus on identified needs; and to clarify needs with respect to their ambiguity, their attributes and metrics, and their supporting evidences.

Needs assessments can be accomplished through several methods, such as operational experiments, exercises, modeling, and simulation of user tasks/operations. (MITRE CORPORATION, 2014)

D.3.3 Mission requirements

ISO et al. (2010) define requirements as conditions or capabilities that must be met or possessed by a system, system component, product, or service to satisfy an agreement, standard, specification, or other formally imposed documents. INCOSE (2015) defines requirements as formal structured statements that can be verified and validated and that may be more than one requirement defined for each need. NASA (2007) adds that requirements are expressed as 'shall' statements and specify quantities for specific periods of time or at a specified time. Furthermore, NASA (2007) indicates that sets of requirements should be adequately related with respect to terms used, not redundant, and non-conflicting among them.

Mission requirements are a set of quantitative expressions that derive from mission objectives, programmatic constraints, and assumptions. They represent a balance between what is wanted and what is feasible within the constraints. Mission requirements are the basis for subsequent requirements on the system and subsystems through the design process. (FORTESCUE et al., 2011; LARSON et al., 2009; LEY et al., 2009; NASA, 2007; WERTZ; LARSON, 2005)

Wertz and Larson (2005) state that although mission objectives may change slightly or not at all during initial activities of the systems engineering effort, mission requirements often change during the design process. Furthermore, they indicate that mission requirements should be traded as the space system definition is becoming clearer. They add that requirements trading is extremely important to a cost-effective mission. However, it is often omitted in the normal process of defining mission requirements. Finally, they add that mission analysis should be the process by which mission requirements are defined and refined in order to meet the mission objectives.

Mission requirements should apply for the entire lifecycle of the solution, should be solution-independent, and should be written in stakeholders language. Specifically, they should state what must be done in operational terms to address both the functional (capabilities) and nonfunctional needs of the stakeholders. Normally, each functional requirement entails at least one nonfunctional requirement, which tend to state how well the function must perform. Mission requirements can be called ‘stakeholder requirements’ or ‘operational requirements’. (LARSON et al., 2009)

Larson et al. (2009) describe that mission requirements can be ranked relative to one another or relative to their value to the mission. In the first case, requirements are ranked in a numerical sequence from 1 to the total number of requirements. They state that this technique gives information about the importance of each requirement; however, it is not always easy to be so precise. In the second case, which is more common, the requirements are grouped into the following three categories:

- Essential: these requirements represent the critical and non-negotiable criteria that the system shall meet to be acceptable. These requirements drive trade studies and must be agreed by all stakeholders;

- Conditional: these requirements would enhance the system value, but their absence would not make the system unacceptable;
- Optional: these requirements may or may not be worthwhile.

Examples of mission requirements are coverage continuity, coverage frequency, coverage duration, field of view, ground track, area coverage rate, viewing angles, earth locations of interest; detection; persistence; geo-location; timeliness; responsiveness; lifetime; availability; survivability; reliability; autonomy; data distribution; data content, form, and format; cost; schedule; regulations and political constraints (e.g. treaties, launch safety restrictions, international allocation); subjects quantity; subjects characteristics (e.g. spectral, radiometric, geometric, temperature, frequency, chemical composition); ground segment interfaces; and ground station locations. (FORTESCUE et al., 2011; LARSON et al., 2009; LEY et al., 2009; WERTZ; LARSON, 2005).

D.3.4 Space system operational concept and architecture

The operational concept (OpsCon) is a vision of how the needs and objectives will be met. It is a verbal or graphical description of a day in the life of the system that will be developed, which derives from mission requirements and constraints. (LARSON et al., 2009; LEY et al., 2009; SAGE; ROUSE, 2009; WERTZ; LARSON, 2005)

The operational concept is also referred as the 'Concept of Operations (ConOps)', 'operations concept', and 'mission concept'. Furthermore, those terms are often used interchangeably in references such as Larson et al. (2009), NASA (2007), ECSS (2009b), and Wertz and Larson (2005). However, according to INCOSE (2015) and ISO et al. (2011), the terms 'operational concept (OpsCon)' and 'Concept of Operations (ConOps)' are different. Specifically, on the one hand, ISO et al. (2011) describe that the Concept of Operations is developed at the organization level and it describes the intended way of operating the organization in order to achieve the organizational goals and objectives. On the other hand, they describe that the operational concept describes in a high-level manner the operational features that are to be provided by the future system. The level of detail should be sufficient to fully explain how the proposed system is envisioned to operate in fulfilling needs and requirements. Furthermore, they explain that the operational concept should provide details about the system such as the major elements of the system and the interconnections among those elements, the operational environment, interfaces to external systems, capabilities and functions of the proposed system, and the operational scenarios. INCOSE (2015) highlights that the operational concept is just one of the life cycle concepts and it covers specifically the system use or operations stage. Differently, Larson et al. (2009) and NASA (2007) describe that operational concepts covers the development, test, deployment, use, and disposal lifecycle stages of the system.

Within this work, the use of the term operational concept is in accordance with ISO et al. (2011) in its meaning and scope.

Important components of an operational concept are the operational scenarios. Operational scenarios are step-by-step descriptions of how the proposed system should operate and interact with its users and its external interfaces under a given set of circumstances. Operational scenarios help to understand how all the pieces interact to provide operational capabilities and provide operational details for the proposed system. Typically, several operational scenarios should be developed, such as one for normal operation, one for exception handling, and one for degraded operations. Operational scenarios should describe events, actions, information, and interactions as appropriate to enable the understanding of the operational aspects of the proposed system. (ISO et al., 2011)

Other components that are typically contained in an operational concept are the timelines (NASA, 2007; WERTZ; LARSON, 2005). NASA (2007) describes that timelines provide the basis for defining system configurations, operational activities, and other sequenced related elements necessary to achieve mission objectives. NASA (2007) adds that timelines mature along with the design effort, starting as a simple time-sequenced order of the major events and ending as a detailed description of lower elements operations during all major mission modes or transitions.

Operational concepts are important to understand requirements or to identify the need for a particular requirement, but they are not requirements. Operational concepts evolve as the design effort advances and guide how the system and interfaces are developed. Operational concepts are developed in a creatively manner based on a set of goals, experience, and expertise of systems engineers, users, operators, and other development teams. (LARSON et al., 2009; SAGE; ROUSE, 2009)

Another important term widely used in systems engineering is the term 'architecture'. INCOSE UK (2015) defines that the architecture of a system architecture is its fundamental structure. The Oxford Dictionary (2016) defines a structure as the arrangement of and relations between the parts or elements of something complex. Ley et al. (2009) describe the space system architecture as the arrangement of elements (e.g. ground stations, satellites, communications architecture, user, and mission operations center) and their interactions.

It should be noticed that previous descriptions of operational concepts include the major elements of the system and their relationship, and consequently they are embracing to the term of architecture. Within this work, both terms are used together since their conceptions are strongly related. This is specially the case for the space systems within the scope of this work (i.e. satellite systems). As Larson et al. (2009) state, systems engineers, users, operators, and other development teams often have an implementation concept and system elements in mind, based on legacy systems and experience with similar systems. This is referred by Larson et al. (2009) as the reference or generic architecture. They describe that the generic architecture is a partition of the system into elements without specifying the performance characteristics of such elements. They add that an example of generic architecture of a system can be a telescope, a pressure tank, and a propellant tank, without giving details to those components.

Jon Sellers et al. (2004) reaffirm the aforementioned idea by stating that in the 'real world', few space missions begin with a totally blank sheet of paper. Typically, at least one of the mission elements is completely defined, or severely constrained by economic, political, or other factors at the outset. They state that mission operations are typically constrained at the beginning of mission design in some way, that space missions typically must use existing facilities, and finally, that normally, the most unconstrained element of a space mission is the spacecraft.

Finally, Larson et al. (2009) state that preconceived notions of the system have drawbacks, such as impede innovative thinking and technology applications, inventive packaging ideas and architectures, and ways of creating new system capabilities.

Ley et al. (2009) describe that a number of rough operational concepts should be developed to meet the mission requirements under the given constraints. They add that those operational concepts will reveal differences in their elements and/or in the interrelationship between them. Different ways of relating the elements, for instance the space element and the ground stations, lead to different operational concepts. NASA (2007) states that cost and schedule constraints will ultimately limit how long a project can maintain multiple architectural concepts. Finally, Ley et al. (2009) state that for a very strict set of constraints, it might be possible to have only one architecture capable of fulfilling the mission objectives.

Wertz and Larson (2005) describe that the space system operational concept and architecture cover the subject, the satellite (payload and platform), launch system, orbit, ground system, communications architecture, and mission operations. They add that it must be defined how data is generated, collected, distributed, and used; how the various components of the space system talk to each other; how the system decides what to do in the long- and short-term (i.e. tasking, scheduling, and control); and the timelines.

Jon Sellers et al. (2004) state that subjects can be characterized by features such as color, size, shape, temperature, chemical composition, or frequency. Knowing such features of the subject enables the subsequent definition of payload requirements.

Ley et al. (2009) state that the orbit is essential for conceptualizing a space system. Wertz and Larson (2005) add that orbit selection and design should be performed to meet the largest number of mission requirements at the least possible cost, so the first step in designing orbits should be determining the effect of orbit parameters on key mission requirements. Similarly, Ley et al. (2009) state that the architecture of the space system should be analyzed with regard to compliancy with the mission objectives. Ley et al. (2009) describe that simulation tools can be used to quantify the degree of compliancy through the use of performance criteria, figures of merit, and measures of effectiveness. In this way, it is possible to judge the expected value of the mission. This is known as mission analysis and the results of such analysis can lead to the modification of requirements and of the selected mission architecture.

For developing operational concepts and architectures, several tools are used such as WBS, N2 charts, sequence or activity charts, functional flow block diagrams, structure charts, allocation charts, data flow diagrams, object diagrams, context diagrams, storyboards, entity-relationship diagrams, data structure diagrams, states and modes diagrams, IDEF0 diagrams, interface definition documents, behavioral diagrams, timelines, functional failure modes and effects tables, sketches, and drawings. (ISO et al., 2011; ISO; IEC, 2011)

D.3.5 System requirements

The definition of requirement is in section ‘D.3.3 Mission requirements’.

INCOSE (2015) defines system requirements as the statements that define what the system requires to do, how well, and under what conditions in order to meet project and design constraints. For a space system, Ley et al. (2009) state that system requirements represent the fundamentals for the configuration of the space system segments (e.g. space, ground, and launch).

Sage and Rouse (1999) state that the system’s major functions can be identified by examining the operational concept. As Larson et al. (2009) state, it is not possible to write operational-concept statements as ‘shall’ statements and turn them into requirements. Consequently, Larson et al. (2009) describe that requirements capture functions that the system needs to do or features it must have to meet the operational concept. They state that system requirements are developed from the system operational concept and architecture and from the mission requirements.

Larson et al. (2009) state that system requirements are written from the system’s point of view and that the relationship between mission requirements and system requirements may be one-to-one, one-to-many, or many-to-one. However, they describe that usually there are more system requirements than mission requirements. They state that the translation from mission to system requirements is often the weakest link in the implementation of systems engineering principles. Furthermore, they describe that capabilities and non-functional features declared as mission requirements translate into different types of system requirements. Table D.3 illustrates such relationship between mission and system requirements.

Table D.3 - Relationship from mission to system requirements.

Mission requirements	System requirements
Capabilities	System input requirements System output requirements System functional requirements
Non-functional features (including constraints)	System performance requirements System usability and quality requirements Cost and schedule requirements Technology constraints and requirements Physical requirements System assurance-related requirements System safety and security requirements Other requirements

Source: Adapted from Larson et al. (2009).

Larson et al. (2009) describe that the translation of capabilities is supported by operational scenarios (or use-case scenarios) and interaction diagrams (sequence diagrams or swim-lane diagrams) while the translation of non-functional features and constraints is supported by activities such as market analysis, benchmarking, modeling/prototyping and simulation, trade-offs, and quality functional deployment.

Wertz and Larson (2005) state that the process for obtaining system requirements begins with the flow of mission requirements to payload requirements and the mission operations to a payload operations conception, which defines how the specific set of space instruments (and possibly ground equipment or processing) will be used to meet the end goals. Wertz and Larson (2005) state that the process begins with the payload because it is the critical element governing the spacecraft performance.

Jon Sellers et al. (2004) define that the satellite payload requirements derive from the previous definition of the subject of the mission. Ley et al. (2009) add that several requirements for the satellite platform result from the payload and the operational concept.

Wertz and Larson (2005) describe that system requirements should be decomposed and allocated into progressively lower levels elements. They state that ideally, system requirements are the basis for segment requirements, and thus, system requirements should come before the later. However, they describe that once segments are defined, there may be trade-offs required at the system level in response to cost, interface issues, performance limitations, or schedules related to segment designs. Finally, they add that system requirements should have margins to permit meeting realistic performance and reliability with minimum risk and that numerical attributes of requirements should evolve during the design process (even when the latter is not a frequent practice). Table D.4 lists some examples of requirements for the space system and its elements.

Table D.4 - Space system requirements examples.

SPACE SYSTEM REQUIREMENTS
• Use of specific ground stations • Use of specific mission control center • Availability during the operational lifetime • Necessary ground operation activities • Arrangement and implementation of command sequences • Operational lifetime • Development time • Fixed cost limit • Funding model • Cooperation with national or international partners • Compatibility with particular ground stations • Use of particular technologies • Time coverage of target regions (space segment / satellite) • Area coverage of target regions (space segment / satellite) • Communication with the ground segment (space segment / satellite) • Operational life span in orbit (space segment / satellite) • Orbit (space segment / satellite) • Period without ground contact (space segment / satellite) • Degree of autonomy (space segment / satellite) • Duration of survival without ground contract (satellite) • Modes of operations (satellite) • Stereo capability (satellite payload) • Different viewing angles (satellite payload) • Integer relationship between the ground pixel sizes of different instruments (satellite payload) • Data products (satellite payload) • Data processing algorithms (satellite payload) • Transporting the payload to the target orbit (satellite platform) • Performing the required orbital maneuvers (satellite platform) • Keeping the payload in the required orbit or position (satellite platform) • Keeping the payload mechanically stable and independent of internal and external disturbances (satellite platform) • Pointing the payload with the necessary accuracy (satellite platform) • Keeping direction without jitter (satellite platform) • Avoiding prohibited directions (satellite platform) • Supplying the payload with electrical power (satellite platform) • Keeping the temperatures within the allowed ranges (satellite platform) • Controlling the payload so it can collect appropriate data (satellite platform) • Acquiring housekeeping data of the payload and transmitting it to the user (satellite platform) • Store and forward capacities (ground segment) • Ground station operations (ground segment) • Contact time (ground segment) • Data processing and archiving capabilities (ground segment) • Data dissemination (ground segment)

Source: Adapted from Ley et al. (2009).

D.3.6 System specification

ISO et al. (2010) define a specification as a detailed formulation, which provides a definitive description of a system for the purpose of developing or validating the system. Similarly, NASA (2007) adds that a specification prescribes completely, precisely, and verifiably the requirements, design, behavior, or characteristics of a system or system component.

The MITRE Corporation (2014) describes that the difference between requirements and specifications is that the former define problems while the latter define solutions.

As Ley et al. (2009) describe for a customer-contractor relationship, the product requirements of the customer are accommodated by the contractor in the form of a design specification for such product.

Within this work, in accordance with the aforementioned descriptions, system requirements will refer to conditions or capabilities that the systems engineering group determined that the system or system elements must meet or possess. On the other hand, system specifications will refer to detailed descriptions of the space system and its elements that the turnkey satellite manufacturers and engineering disciplines groups established for the space and ground segments as a solution for meeting the imposed requirements.

D.3.7 Plans

ISO et al. (2015b) define plans as information items that present a systematic course of action for achieving a declared purpose, including when, how, and by whom specific activities are to be performed. Similarly, Larson et al. (2009) describe that any plan includes what to do, who will do it, when the work must be complete, and how many resources will be available to do it.

NASA (2007) describes that plans should be updated as necessary through the lifecycle stages to reflect the current environment and resources and to control the project performance, cost, and schedule.

INCOSE (2015) describes that plans enable activities such as developing a project schedule based on objectives and work estimates; defining required infrastructure and services; defining costs and estimate project budget; defining the strategy for procurement of materials, goods, and enabling system services; defining the technical effort and the reviews that will be performed; defining source documents and deliverables (e.g. RFP, standards, requirements, system specification); and establishing the criteria to be used for major milestones, decision gates, and internal reviews.

Larson et al. (2009) describe that a space system development requires as a minimum a project management plan, a systems engineering management plan, a test plan, and a verification and validation plan. They define that the project management plan is the overall plan leading the project and that the systems engineering management plan or SEMP is the plan that governs the technical work (including test and verification efforts). Larson et al. (2009) add that systems engineers are mainly responsible for producing the systems engineering plan; however, they require involvement of other participants in the project. Finally, INCOSE (2015) adds that the systems engineering management plan can also be referred as the systems engineering plan or SEP.

The systems engineering plan is the top-level plan for managing the systems engineering effort. It describes how the systems engineering effort, in the form of tailored processes and activities, for one or more life cycle stages, will be managed and conducted in the organization for the actual project. It involves the definition of issues such as the systems engineering processes, functional analysis approaches, what trade studies will be included in the project, schedule, and organizational roles and responsibilities. It is a living document that must be updated as the project changes and kept consistent with the project plan. (INCOSE, 2015)

The systems engineering plan is the chief technical plan and integrates subordinate plans. The number of distinct subordinate plans depends on the project scale, complexity, strategy, or preferences. However, the systems engineering plan should note how each plan relates to it and it should describe approaches to assure compatibility among subordinate plans. Systems engineers and project managers should identify the additional required technical plans. Furthermore, subordinate plans may be separate plans or may be included within the systems engineering plan. (LARSON et al., 2009; NASA, 2007)

NASA (2007) describes that once the technical work to be done have been defined, estimates on schedule and cost for the technical portion of the project can be assessed. NASA (2007) adds that discrepancies between the project's allocated budget and schedule and the actual cost estimate and schedule must be reconciled continuously throughout the project's life cycle. Furthermore, Larson et al. (2009) state that deviations between plans and reality often happen.

According to Wertz and Larson (2005), another relevant plan is the mission operations plan. Its development is similar to that of the operational concept. However, they add that the mission operations plan is more detailed and emphasizes the way that the space system is operated and how the spacecraft and ground operations are performed. They describe that mission operations plan usually results from the cooperative work of several disciplines and becomes more detailed as the design effort progresses. They add that this plan follows from and must be consistent with the operational concept. They also state that the mission operations plan is closely related to the mission concept and to the design of the space and ground elements.

Table D.5 illustrates several plan examples according to Larson et al. (2009), NASA (2007), ECSS (2009a), ECSS (2010), ECSS (2009b), and ECSS (2008a).

Table D.5 - Examples of plans listed on different references.

PLANS
• Acceptance plan • Acquisition plan • Activation and check-out plan • Activity plan • Alignment requirements and control plan • Assembly, integration, and test plan • Assembly, integration, and verification plan • Asset management plan • Audit plan • Baseline plan • Build plan • Capacity plan • Cleanliness and contamination plan • Closure plan • Communication plan • Configuration management plan • Cost account plan • Cost estimating plan • Data management plan • Deployment plan • Design and analysis cycle plan • Development plan • Disposal plan • Documentation management plan • Domain engineering plan • Earned value management plan • EMC/EMI control plan • Engineering plan • Fracture control plan • Implementation plan • Improvement plan • Industrial procurement plan • In-flight check-out plan • Information management plan • Information security plan • Inspection plans • Installation plan • Integrated Logistics Support plan • Integration plan • Interface control plan • Launch and Early Orbit Plan • Launch operations plan • Launch site operations and logistics plan • Life-cycle cost management plan • Logistics support plan • Maintenance plan • Manufacturing and assembly plan • Manufacturing plan • Mass properties control plan • Measurement plan • Microgravity control plan • Milestone payment plan • Mission operations plan • Noise control plan • Off-the-shelf plan • Operations plan • Orbital debris mitigation plan • Payload-to-carrier integration plan • Product assurance plan • Production plan • Program plan • Project plan • Project protection plan • Qualification plan • Quality assurance plan • Quality control plan • Radio frequency plan • Release plan • Reuse plan • Reliability, maintainability, and supportability plan • Reliability plan • Requirements management plan • Review plan • Risk control plan • Risk management plan • Risk mitigation plan • Safety and mission assurance plan • Sampling plan • Security aspects verification plan • Service continuity and availability plan • Service management plan • Service plan • Source evaluation plan • Spacecraft systems analysis plan • Strategic plan • Surveillance plan • Software development plan • Software IV&V plan • Software management plan • Supportability plan • System and subsystem test plan • System calibration plan • System commissioning and operation support plan • System performance simulations plan • Systems analysis plan • Systems engineering plan • Technical measurement plan • Technical review plans • Technology development plan • Technology plan • Test plan • Training plan • Validation plan • Verification and validation plan • Verification plan

It should be noticed that some of the plans that are shown in the table might refer to the same content even when they differ in name according to the different references.

Source: Author production.

D.3.8 Evaluation reports

ISO et al. (2015b) define reports as information items that describe the results of activities such as investigations, observations, assessments, or tests.

Evaluation reports provide results of reviews and evaluations. They include evaluation criteria and provide information and recommendations to assist future decision-making. They also may indicate trends and recommendations for future comparable situations. Examples of evaluation reports are risk assessment, evaluation of design constraints, suppliers, customer satisfaction, effectiveness of security controls, analysis of change records or change requests, or financial variances. Furthermore, examples of criteria for evaluations can be traceability, consistency, testability, risk reduction, usability, customer satisfaction, and feasibility. (ISO et al., 2015b)

According to Jon Sellers et al. (2004), criteria for assessing space missions and any other problems reduce to a ‘trade-space’ represented by cost, schedule, and performance. Similarly, Ley et al. (2009) describe that a criteria for analyzing space system architectures should be the compliancy with mission objectives. Furthermore, Ley et al. (2009) describe that with the help of simulation tools the degree of compliancy should be quantified and pointed out. If possible, performance criteria, figures of merit, and measures of effectiveness should be used to judge the expected value of the mission.

Within this work, main evaluation reports are the feasibility and utility reports.

ISO et al. (2010) define utility as a measure of value within a given value system. Similarly, Diller (2002) defines utility as a measure of goodness of a design. He describes that the ideal design is the one that creates the most utility. Furthermore, he adds that typically, the creation of the utility arises from the fulfillment of several different attributes.

Within this work, utility is used in accordance with ISO et al. (2010) and Diller (2002) definitions. Consequently, utility reports represent results of utility (or goodness) measures of alternatives.

Similarly, ISO et al. (2010) define feasibility as the degree to which requirements, designs, or plans for a system can be implemented under existing constraints. ECSS (2009a) refers to feasibility as technical and programmatic feasibility. Finally, Roedler and Jones (2005) describe that assessing feasibility aims to look at the basis of estimations, realism of adjustments, confidence in estimation and estimation techniques, validity of or changes in assumptions, changes in project/product attributes that may affect the estimate, and comparisons of related key performance parameters or other relevant parameters.

Within this work, feasibility is used in accordance with the aforementioned ideas of ISO et al. (2010), ECSS (2009a), and Roedler and Jones (2005). Consequently, feasibility reports represent results of feasibility assessments in terms of programmatic and technical aspects.

D.3.9 Requests

ISO et al. (2015b) define requests as information items that record information needed to solicit a response.

PMI (2008) refers to requests that are used to solicit proposals from prospective sellers as procurement documents. It describes that such information items are utilized in bid and proposal activities. Specifically, according to PMI (2008), terms such as bid, tender, or quotation are generally used when the seller selection decision will be based on price (as when buying commercial or standard items), while a term such as proposal is generally used when other considerations, such as technical capability or technical approach are dominant.

PMI (2008) states that different terms are used for different types of procurement requests, such as: Request For Information (RFI), Invitation For

Bid (IFB), Request For Proposal (RFP), Request For Quotation (RFQ), tender notice, invitation for negotiation, and seller initial response. ECSS (2009a), ISO et al. (2015b), and ISO (2011) employ other terms such as Invitation To Tender, acquisition requirements, acquisition documents, Call For Proposals (CFP), and request for tender. As PMI (2008) explains, the procurement terminology may vary by industry and location of the procurement.

PMI (2008) adds that the buyer structures procurement requests to facilitate an accurate and complete response from each prospective seller and to facilitate easy evaluation of the responses. These requests include a description of the desired form of the response, the relevant procurement Statement of Work (SOW), and any required contractual provisions.

Table D.6 describes some examples of procurement requests and their description.

Table D.6 - Examples of procurement requests.

PROCUREMENT REQUESTS	
Request For Information (RFI)	**Used for requesting various pieces of information related to a product, service, or seller capability from potential sellers** (PMI, 2008)
Request For Proposal (RFP)	**Used for requesting proposals of products or services from potential sellers.** (PMI, 2008) **Synonyms of RFP are Invitation For Bid (IFB), acquisition requirements, acquisition document, Call For Proposals (CFP), Invitation To Tender (ITT), request for tender.** (HULL et al., 2005; ISO et al., 2015b; PMI, 2008)
Request For Quotation (RFQ)	**Used for requesting price quotations of common or standard products or services from potential sellers. Sometimes used in place of RFP.** (PMI, 2008)

Source: Author production.

D.3.10 Proposals

ISO et al. (2015b) define proposals as information items prepared by potential suppliers to support the response of a request. They state that proposals include cost, schedule, risk statements, the methodology to satisfy the request, experiences and capabilities, any recommendations to tailor the request or contract, and the signature of the supplier’s approving authority.

ISO et al. (2015b) state that proposals can be prepared by suppliers that can be both inside or outside of the requesting organization.

São José dos Campos/SP - 18,19 e 20 de agosto de 2015

ATTACHMENT E - PREVIOUS PUBLISHED WORK

Possible benefits of a COTS-based process on a satellite remote sensing mission based on software industry results

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Abstract. This work consisted of a brief review on the benefits of COTS items and COTS-based processes. It shows that considerations taken by software industry could be applied in space industry for the development of satellite remote sensing missions through an ad-hoc COTS-based process.

Keywords: Remote Sensing; Satellites; COTS.

1. Introduction

Since 1990, the use of commercial off-the-shelf (COTS) products as elements of larger systems is becoming increasingly. That tendency has generated some modifications around the traditional development processes in order to develop a new development paradigm around COTS items [Morisio et al., 2002]. This work shows a brief review about the benefits of using COTS items and having a COTS-based development process. It presents some COTS-based approaches used in software and space industry, and finally, it is expected to show that some approaches made in software industry, could be useful for the development of a satellite remote sensing mission.

2. Results and Discussion

COTS is a term attributed to hardware and software that is commercially made and available to the general public and that requires little or no unique modifications to meet the needs of the customer [Gansler and Lucyshyn, 2008]. The benefit of COTS items is that they already exist, so there is no need of invent them [Larson, 2009]. As a result, in software industry, COTS based software development has been gaining force as an alternative strategy to in-house development as an effort to reduce implementation, operating, and maintenance cost and time [Lin et al., 2006]. A COTS based software development refers to a process that integrates pieces of prebuilt software (COTS packages) into a system to provide some functionality. On some traditional approach, selection of COTS (one of development process phases according to Morisio et al. [2002]) has been performed after the requirements gathering and the development of system architecture and design, and has presented two disadvantages: it narrows the search of suitable COTS products to a very limited few that only can fit within the anticipated design; and, it requires more time invested prior to proceeding with COTS products evaluation and selection [Lin et al., 2006].

In the space industry, the ECSS-Q-ST-20-10C standard describes activities for the off-the-shelf items utilization in space systems. It shows a selection process when a supplier realizes the possibility of using COTS, and defines that is necessary firstly to establish preliminary equipment specification. Then, each COTS candidate could be compared to the project requirements in order to have a preliminary make or buy decision. It is only at the Preliminary Design Review (PDR), that a final make-or-buy decision is taken and later it is when the procurement activities can begin [ECSS, 2010].

As an analogy to software development, COTS based satellite development could refer to a process that integrates pieces of prebuilt items (COTS equipments) into a system (satellite) to provide some functionality. From this analogy, and due to similarity on the moment that COTS selection is performed, disadvantages already described for software process can be extrapolated to the ECSS process.

Also in software industry, different approaches have been already proposed to avoid the described problems. In one of them [Lin et al., 2006], the COTS evaluation is performed earlier in the project just after requirements gathering and this allowed the exposure of new capabilities and technologies that could assist in improving the design and business practices. In other, the realization of COTS selection is done together with requirements analysis [Morisio et al., 2002]. Both processes, points to a common factor: performing the COTS analysis earlier in the development process.

Currently, several COTS options for components, subsystems, payloads, platforms or even satellites can be found on satellite remote sensing manufacturers' webpages (such as www.sstl.co.uk), so it seems that a customized process for the development of satellite remote sensing missions could bring the benefits that software industry have discovered.

3. Conclusion

Due to the advantages of the use of COTS items, the current availability of several COTS items at different levels in the satellite remote sensing market, and the disadvantages of the traditional development process, this paper proposes the creation of an ad-hoc process to be used in satellite remote sensing missions.

Acknowledgments: The author thanks CAPES for financial support.

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