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International and Brazilian Air Force's requirement definition processes for space systems

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Abstract— **The development of a system begins with the comprehension of its mission and the gathering of the expectations and needs of all involved parties. Transforming these into a set of complete and coherent requirements is essential for the mission's success. That is even more true in the space systems' context due to the high costs associated with tardiness in finding and correcting mistakes. The Brazilian Strategic Program of Space Systems (PESE) presents the guidelines for the long-term implementation of space systems projects. It demands that the definition and development of space system missions must follow Brazilian Air Force's DCA 400-6 guideline and, when appropriate, other international standards. This article presents a brief survey and analysis of some available system and requirement engineering processes that could be used as guidelines to the conceptualization of a system, such: DCA 400-6, Brazilian Defense Ministry Manual MD40-M-01, INCOSE SE Handbook, ISO/IEC/IEEE 15288:2015, and NASA SE Handbook.**

Keywords— **Systems Engineering, DCA 400-6, Space Systems.**

I. Introduction

Location, navigation, communication, or meteorology are examples of space system missions which are essential to modern daily life. Brazilian Air Force (FAB) recognizes the importance of those systems also for the nation's defense and prosperity. The FAB's manual "MCA 16-3 - Projects Classifications into Levels of Monitoring"(in Portuguese, MCA 16-3 - *Classificação de Projetos em Níveis de Acompanhamento*) [1], classify all the space systems projects (as well as the aircraft and weapon systems) in the highest level of importance, due to their relevance to the maintenance and expansion of the combat capacity or the C^4ISR (Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance) strategic capacity.

In order to set forth the guidelines for the long-term implementation of space systems projects in Brazil, FAB published, in 2018, the Strategic Program of Space Systems (PESE, in Portuguese - *Programa Estratégico de Sistemas Espaciais*) [2]. PESE provide for six programs aiming for launching satellites in low orbit and three programs for launching satellites in geostationary orbit. These programs aim to fulfill the Brazilian high demand for communications services, environmental monitoring, meteorological data, and the capture of strategic images. PESE also identifies the need for creating those satellite architectures and the need for qualifying the FAB personnel to perform the space system specification, development, operation, manufacturing, and support.

However, space systems development often implies high-cost projects, with high levels of complexity and risks. A transdisciplinary and integrative approach, such as System Engineering, is important to maximize the mission's probability of success. Nevertheless, in order to be successful, it is essential to capture the stakeholders objectives and needs, in addition to have the capability of transforming them into a coherent, comprehensive, and well-stated set of formal requirements during the beginning of the system life cycle. Several bibliographies [3]–[8] present the importance of having processes and methodologies to guide the system's development in early life-cycle phases when requirements are being defined. That need is even more clear in space systems, a context in which a mission failure often results in high investment losses.

Regarding the development of a space system, PESE requires that FAB's "space systems life cycle processes must follow the DCA 400-6 and, when appropriate, the processes used by other countries in the definition and development of space system missions" [2].

DCA 400-6 - Air Force's Material and System Life Cycle"(in Portuguese, DCA 400-6 *Ciclo de Vida de Sistemas e Materiais da Aeronáutica*) [9] is a FAB guideline whose purpose is to guide the planning and execution of the phases and main events throughout the life cycles of all Brazilian Air Force's systems and materials, as well as establishing the competencies and responsibilities of the players in the process.

So, in order to fulfill PESE's mandate, it is important to understand how to use not only the DCA 400-6, but also other appropriate international manuals and guidelines, in the development of space systems. This paper aims to present a survey of system engineering processes focused on requirements definition, and discuss, further, the characteristics and limitation of each process. First, Section II presents the DCA 400-6 life cycle phases, with special attention being drawn to the ones that lead to the system conceptualization. Then, Section III discusses the manual for life cycle management recently published by the Brazilian Defense Ministry, and Section IV presents an overview on well-known international system and requirement engineering processes, namely the ISO/IEC/IEEE 15288:2015 [10], the INCOSE SE Handbook [11], the NASA System Engineering Handbook [12], and ECSS-E-ST-10C Rev.1 (2017) [13]. Finally, Section V presents the conclusion and future works.

II. DCA 400-6

Before addressing the DCA 400-6 life cycle process, it is important to consider the major players in the studied process and explain their responsibilities:

- **EMAER.** An entity in FAB's high-administration level whose mission is to advise the Air Force's Commander. In the system's life cycle, EMAER is responsible for the general coordination of the activities prescribed by the DCA 400-6.

- **ODSA.** An entity responsible for controlling a given system/material, for guiding end-users on how to operate the system/material.

The life cycle phases, as proposed by the DCA 400-6, are presented in Fig. 1. This paper is going to address only the Concept, Feasibility, and Definition phases.

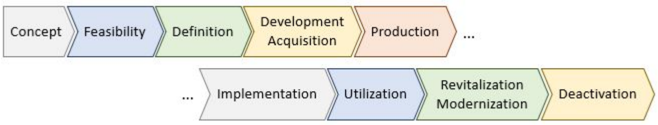

Fig. 1. DCA 400-6 phases. Source: Adapted from [9]

A. Concept Phase

Within this phase, the operational need or technological opportunity is detected and documented, and operational requirements for the mission are defined and documented. The proposed activities for this phase are presented in Fig. 2.

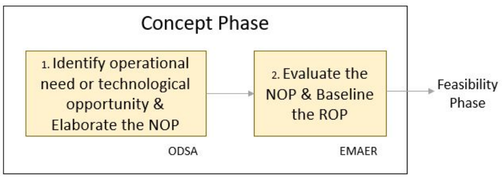

Fig. 2. DCA 400-6 - Conception Phase. Source: Adapted from [9]

The ODSA identifies an operational need or technological opportunity and elaborates a document stating those needs, called Operational Needs (NOP - *Necessidade Operacional*). This document starts the system and material life cycle. These needs are related to those that will inevitably lead to the acquisition, modification, or development of systems which will enable FAB to execute the (current or new) operations that are essential in fulfilling its mission.

The NOP is then evaluated and prioritized by EMAER taking into consideration the FAB's Political and Strategic Conception and the available budget, and transformed into a second document, namely the Operational Requirement (ROP - *Requisito Operacional*). This document is issued by EMAER, with contribution from the ODSAs that have a particular interest in the system and material besides having the appropriate technical expertise [14]. The ROP should describe the performance desired for the system, considering the mission and application for the system and safety when operating.

In 2019, FAB issued the manual 'MCA 16-9 - Development of the Operational Requirements - ROP EMAER"(MCA 16-9 - *Elaboração de Requisitos Operacionais - ROP EMAER* [14] to guide the elaboration of the ROP. This manual presents the main concepts guiding the requirement elicitation and definition, and the ROP structure. It also presents the operational requirements as high-level requirements, i.e., as sentences that translate the problem identified in the NOP into Requirement Engineering language.

B. Feasibility Phase

Within this phase, the alternatives to fulfill the needs are evaluated, considering risk, schedule and cost-effectiveness. The life-cycle information is obtained, and an RFI (Request for Information) is emitted to reach out to companies and other governments agencies. During this phase, the ODSA may conclude that some requirements are not adequate for the project, especially when an RFI response is received back [14]. The proposed activities for this phase are presented in Fig. 3.

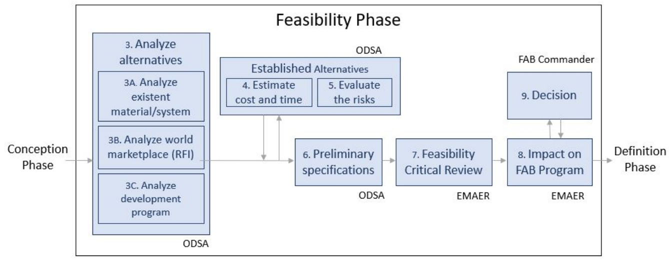

Fig. 3. DCA 400-6 - Feasibility Phase. Source: Adapted from [9]

C. Definition Phase

Within this phase, a detailed study, including engineering studies, models, and simulations, is performed and preliminary plans towards nationalization are laid out in order to improve the capabilities of companies. Then, the Technical, Logistical, and Industrial Requirements (RTLI - *Requisitos Técnicos, Logísticos e Industriais*) are defined and a project management team is designated. The phase ends when a company or governmental entity is selected to provide the system after the RFPs (Request for Proposals) are issued and analyzed, concluding when the contract is negotiated. In this phase, EMAER also conducts studies with the Secretariat of Economy, Finance, and Administration of the Air Force (SEFA) in order to prospect funding sources for the project. The proposed activities for this phase are presented in Fig. 4.

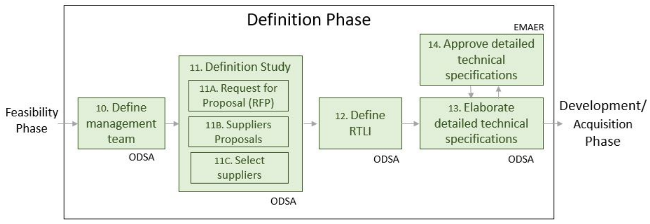

Fig. 4. DCA 400-6 - Definition Phase. Source: Adapted from [9]

Besides those, the Definition Phase also has other subsequent sub-phases whose activities are not presented here, including the Sub-phase of Preparation for Development or Acquisition (elaboration of Plans), Sub-phase of Selection of Companies for the Development or Acquisition, and Sub-phase of Review and Decision.

III. MD-40-M-01

The Brazilian Defense Ministry recently published (2019) the first edition of the manual MD40-M-01 - Manual of good practice for the management of defense system life-cycle (*Manual de boas práticas para a gestão do ciclo de vida de sistemas de defesa)* [15]. The analysis of this document is undoubtedly relevant because all military branches should follow the guidelines of the Defense Ministry. The manual intention is to help the Brazilian military branches in developing their own programs when it comes to life cycle management. Each military branch and its organizations can customize the Life Cycle models to their defense systems at the beginning of the concept phase.

The system engineering basis for the manual was the international standard ISO/IEC/IEEE 15288:2015 - Systems and software engineering – System life cycle processes [10]. The proposed life cycle for the defense system has 6 phases, as presented in Fig. 5, beginning with the Concept phase which builds upon the preliminary operation requirements arising from a previous pre-conception phase (not approached in the manual). The Concept phase is the only one analyzed in this article.

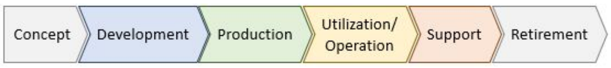

Fig. 5. MD-40-M-01 phases. Source: Adapted from [15]

A. Concept phase

The goal of the concept phase is to evaluate system demands through the development of models to study and analyze the needs assessment carried out in the pre-conception phase, establishing the corresponding system requirements and proposing a feasible solution. The process inputs, main sub-processes, and outputs are presented in Fig. 6.

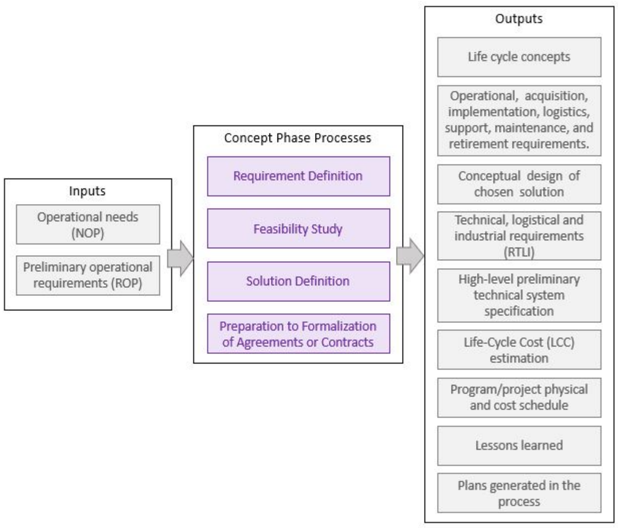

Fig. 6. MD-40-M-01 - Concept Phase. Source: Based on [15]

MD-40-M-01 mentions that the technical process for defining the stakeholder and system requirements should follow ISO/IEC/IEEE 15288:2015 [10] or the process presented in NASA System Engineering Handbook [12].

IV. International System and Requirements Engineering Processes

As mentioned previously, PESE [2] requires that FAB's space systems must follow the DCA 400-6 [9] and, when appropriate, the standards used by other countries. So, besides having knowledge of the DCA 400-6 and its scope, it is important to have a look at the processes proposed by the international system engineering standards, guidelines, and handbooks.

A. INCOSE SE Handbook & ISO/IEC/IEEE 15288:2015

The INCOSE SE Handbook [11] presents itself as consistent with ISO/IEC/IEEE 15288:2015: Systems and software engineering — System life cycle processes [10]. Both documents present four process groups with their respective sub-processes, as presented in Fig. 7.

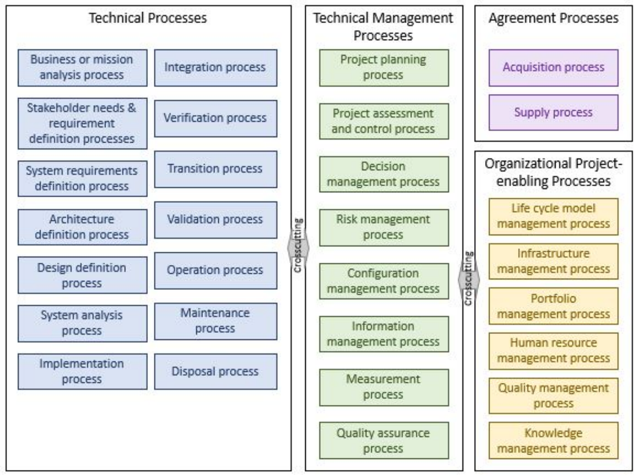

Fig. 7. INCOSE SE Handobook & ISO/IEC/IEEE 15288:2015 Processes. Source: Adapted from [11]

This article is going to focus on the first three Technical processes: Business or mission analysis, Stakeholder needs & requirement definition, and System requirement definition process. Those processes take place in the Concept and Development phases.

Technical processes enable the system engineer to transform needs into a sufficient set of requirements which will result in a system solution. Needs are often capabilities or things that are lacking but are desired by one or more stakeholders. Requirements are formal, structured statements that can be verified and validated [11].

1) Business or Mission Analysis Process: Business or Mission Analysis Process initiates the system life cycle by: (a) defining the problem domain; (b) identifying major stakeholders; (c) identifying environmental conditions and constraints on solution domain; (d) developing preliminary life cycle concepts; and (e) developing the business requirements and validation criteria.

The process inputs, activities, and outputs are presented in Fig. 8.

2) Stakeholder Needs & Requirement Definition Process: After identifying the stakeholders, this process elicits the stakeholder needs that correspond to a new or changed capability or new opportunity. For guidance, the Concept of Operations (ConOps), the system-level preliminary Operational Concept (OpsCon) from the development enterprise and other life cycle concepts are used. The stakeholder needs are then analyzed and transformed into a set of stakeholder requirements. Also in this process, the effects of the solution and its interaction with the operational and enabling environments are made

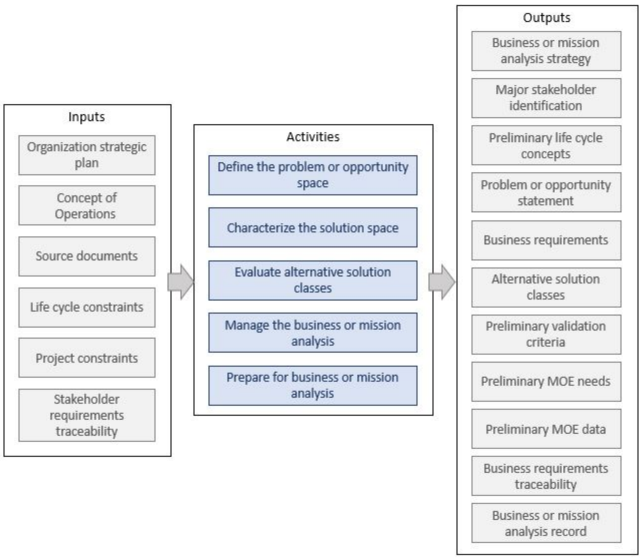

Fig. 8. Business or Mission Analysis Process. Source: Adapted from [11]

explicit. The stakeholder requirements are often captured in a Stakeholder Requirements Specification (StRS).

The process inputs, activities, and outputs are presented in Fig. 9.

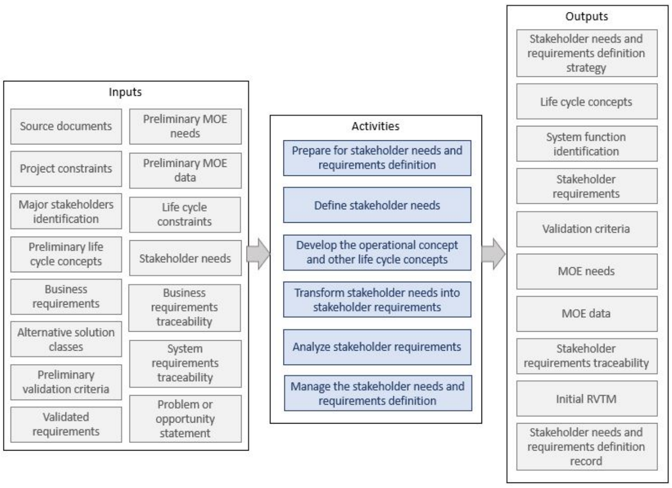

Fig. 9. Stakeholder Needs & Requirement Definition Process. Source: Adapted from [11]

3) System Requirement Definition Process: System Requirement Definition Process transforms the stakeholder requirements baseline presented in the StRS into system requirements, which are often captured in a System Requirements Specification (SyRS).

The system requirements specify the system characteristics, attributes, functions, and performance that will satisfy the stakeholder requirements. They are the basis for the system architecture, design, integration, and verification. A complete, but a minimum set of requirements must be established early in the project life cycle.

The process inputs, activities, and outputs are presented in Fig. 10.

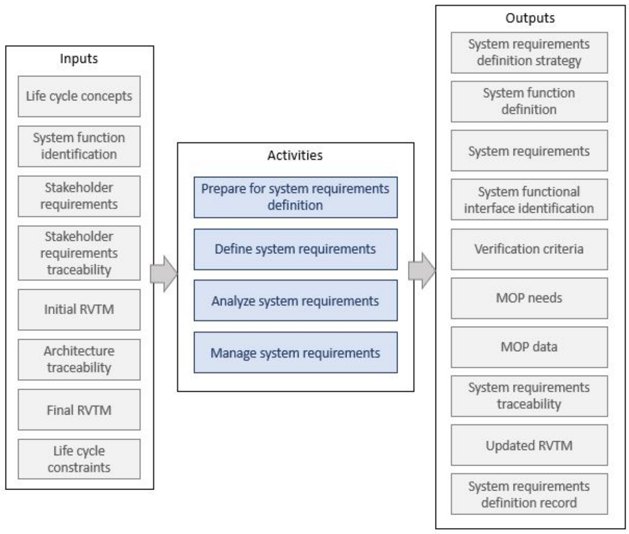

Fig. 10. System Requirement Definition Process. Source: Adapted from [11]

B. NASA System Engineering Handbook

In what follows, we present succinctly the NASA System Engineering Handbook [12] together with NASA NPR 7123.1 System Engineering Processes and Requirements [16].

The handbook presents 17 processes applicable to NASA space flight projects of any size, but the type, size, and complexity of the project will lead to changes in the amount of formality, depth of documentation, and timescales. Those processes are presented in Fig. 11.

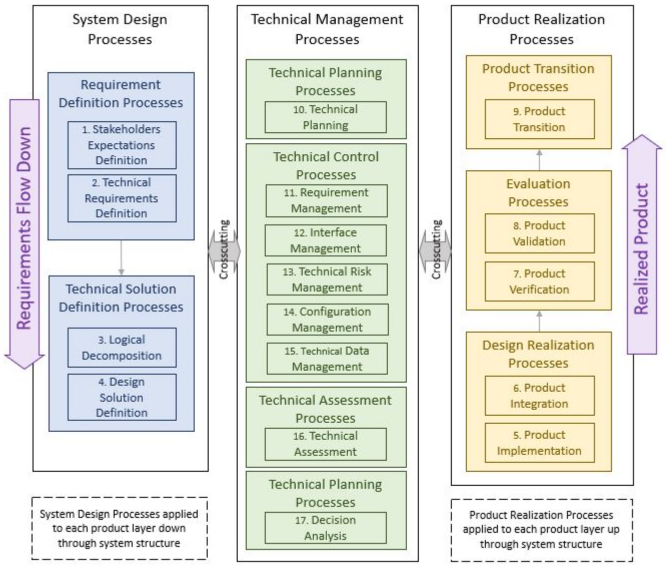

Fig. 11. NASA System Engineering Processes. Source: Adapted from [16]

The processes have the goal of guiding the system engineer through product development up to realization of the end products. They are grouped in three sets of technical processes (System Design Processes, Technical Management Processes, and Product Realization Processes). The System Design Processes are used to define and baseline technical requirements, and, beyond the scope of this work, to decompose the requirements into logical and behavioral models, and transform those technical requirements into a design solution that has to satisfy the baseline stakeholders expectations. The processes are interdependent, highly iterative and recursive, producing a validated set of requirements and a design solution as outputs. This work is going to focus only in the first two processes from the first set of System Design Processes: 1. Stakeholders Expectation Definition, and 2. Technical Requirements Definition.

These processes 1 and 2 take place beginning in the Pre-phase A extending to Phase B from NASA life-cycle. The whole life-cycle is presented in Fig. 12.

Fig. 12. NASA Life-Cycle Phases

In Pre-Phase A, a study team produce and analyze a broad spectrum of ideas and alternative missions, from which new programs and projects that can fall within technical, cost, and schedule constraints can be selected.

Within Phase A, goals and objectives of the project are solidified, such that the feasibility and desirability of the suggested new system are evaluated. As the project is defined, the mission concept baseline is established alongside with a mission and top-level system architecture in response to the program and project expectations, system-level requirements and constraints.

In Phase B, the project achieves enough detailing to allow the establishment of an initial project baseline that includes a project-level performance requirements and a complete set of system and subsystem design specifications for both flight and ground elements.

1) Stakeholders Expectation Definition: This is the first process and establishes the foundation for the system design and product realization. The main purpose is to identify the stakeholders and their expectations for the use of the product. In order to accomplish that, the usual approach is to develop use-case scenarios and ConOps. The process's inputs, activities and outputs are presented in Fig. 13.

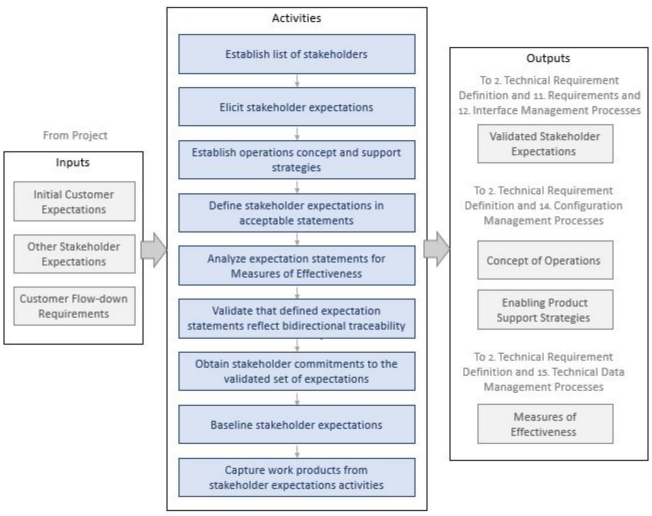

Fig. 13. Stakeholders Expectation Definition Process. Source: Adapted from [12]

2) Technical Requirements Definition: This process defines the problem and transforms the baseline stakeholder expectations into a complete set of validated technical requirements (expressed as "shall" statements). The technical requirements can be used for defining a design solution and related enabling products. Fig. 14 presents the process inputs, activities and outputs. The technical requirements definition activities apply to the definition of all technical requirements from the program, project, and system levels down to the lowest level product and component requirements document.

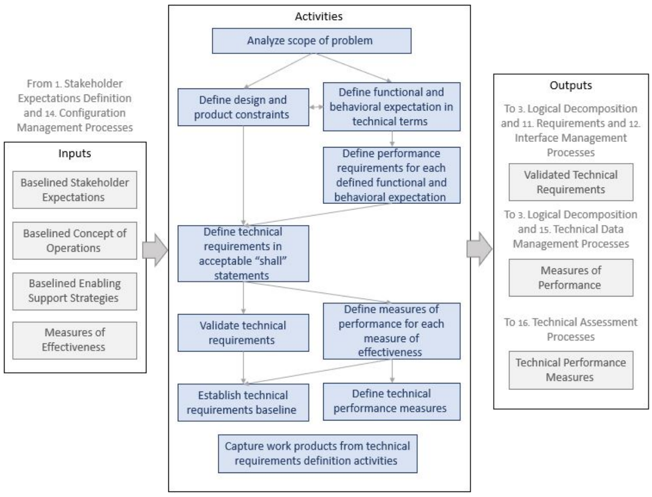

Fig. 14. Technical Requirements Definition Process. Source: Adapted from [12]

C. ECSS-E-ST-10C Rev.1

The goal of the ECSS-E-ST-10C Rev.1 (2017) - Space Engineering: System Engineering General Requirements is to specify the requirements for implementation of system engineering (SE) for space systems and space products development. Its objective is the implementation of a solid technical basis, minimizing technical risk and cost for space systems and space products development [13].

The life-cycle proposed by ECSS is defined in ECSS-M-ST-10C Rev. 1 [17] and presented in Fig. 15. This work only approaches the first three phases.

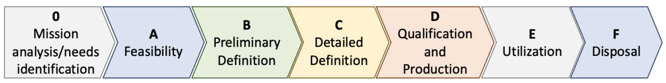

Fig. 15. ECSS Life-Cycle Phases

Phase 0's (mission analysis-need identification) tasks are: (1) to support customer needs' identification; (2) to propose possible system concepts; (3) to support the Mission Definition Review (MDR) and ensures implementation of its actions; (4) to perform an analysis of the Mission Statement document (mission Statement captures the declared user needs), transforming it, with lower level suppliers contribution, in to a Mission Description document(s) (MDD), and maintain the MDD for the final selected concept; (5) to proposes the requirements based on the expressed user needs for agreement with the customer.

Phase A's (feasibility) tasks are: (1) to finalize the needs' expression identified in Phase 0; (2) to propose system solutions (including identification of critical items and risks) to meet the customer needs; (3) to support the Preliminary

Requirement Review (PRR) and ensure implementation of its actions; (4) to finalize the validation of the requirements against the expressed needs together with the customer.

Phase B's (preliminary definition) tasks are: (1) to establish the system preliminary definition for the system solution selected at the end of Phase A; (2) to demonstrate that the solution meets the technical requirements according to the schedule, the target cost and the customer requirements; (3) to support the System Requirements Review (SRR) and Preliminary Design Review (PDR), and ensuring implementation of theirs actions; (4) to define development approach and plan of engineering activities.

1) Requirement engineering process: The process proposed by ECSS-E-ST-10C for requirement engineering encompasses the sub-processes presented in Fig. 16.

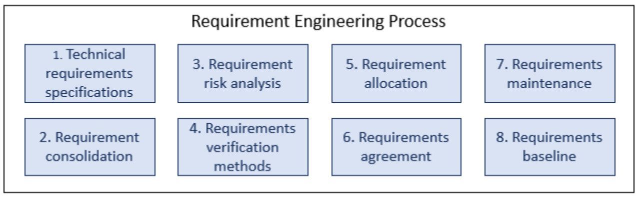

Fig. 16. ECSS-E-ST-10C Rev.1 Requirement Engineering Process

The tasks for the technical requirements specifications subprocess encompass: (a) to establish TS of the next lower level products consistent among them and with the technical specification received from the customer; (b) to ensure that the TS is established according to [18]; (c) to establish a specification tree.

The tasks for the requirement consolidation sub-process encompass: (a) to involve the customer in the requirements' consolidation; (b) to identify and resolve incomplete, duplicate, ambiguous, and contradictory requirements for customer-issued requirements; (c) to reflect the consolidated requirements in the TS.

V. Conclusion

This article presented a survey on some Brazilian and international system and requirement engineering processes. Firstly, it was presented the DCA 400-6 - Air Force's Material and System Life Cycle [9], then the MD40-M-01 - Manual of good practice for the management of defense system lifecycle [15], and lastly, the INCOSE SE Handbook [11] & ISO/IEC/IEEE 15288:2015 [10], NASA System Engineering Handbook [12], and ECSS-E-ST-10C Rev.1 (2017) [13].

Each of these guidelines, manuals, standards and handbooks has a different approach and intended use. DCA 400-6 is a guide for the Brazilian Air Force that exhibit phases and main events for life cycles of all kind of systems and materials independently of size and complexity. It does not present how to accomplish the proposed activities. The manual MD40-M-01 was recently published and, therefore, the military branches still have not had time to adapt theirs specific manuals and guidelines to comply with it. Since the manual was based in the international standard ISO/IEC/IEEE 15288:2015, the nomenclatures used is more broadly understandable. Its main disadvantage is not approaching how the needs and operational (stakeholders and mission) requirements are elicited and defined, both crucial activities for project and mission success. ISO/IEC/IEEE 15288:2015 provides generic top-level process descriptions, as [11] mention, while the INCOSE SE Handbook elaborates on the practices and activities necessary to execute those processes. INCOSE SE Handbook also presents processes for a wide range of application domains, man-made systems and products, as well as business and services, and the user must inevitably tailor it for a specific system, such as a space system. NASA SE Handbook, differently, presents fundamental concepts and techniques of systems engineering applicable to NASA space flight projects (research and development) of all sizes. This way, it can be more easily tailored to the Brazilian space system. ECSSs are standards issued for space projects, and the ECSS-E-ST-10C Rev.1 (2017), in particular, presents the tasks that SE must perform, and the guidelines for the documents produced as outputs of the process (Documents Requirements Definition - DRDs). Future works encompass an in-detail comparison of those processes and, mainly, an evaluation of the suitability of the process established in the DCA 400-6 for application in complex space systems. Also, it would be desirable to verify whether the DCA 400-6, especially with respect to the requirement and conception phase, is up-to-date and consistent with the presented well-established international system engineering principles.

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