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Methodology for requirements definition of complex space missions and systems

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ABSTRACT

The paper deals with the description of a methodology to properly perform space mission design, with particular attention to derivation of requirements.

Several tools are usually adopted to support the design of complex missions and systems, but no very rigorous processes are available for the derivation of requirements. The methodology proposed in this paper aims at providing a general approach to exploit the main system engineering analyses and tools for a thorough assessment of the requirements. Specifically, it addresses how each category of requirements can be derived by appropriate analyses and what is generally the sequence of derived requirements categories.

The very first design step is mission statement and objectives definition. A parallel activity is the stakeholders' needs' analysis, mainly based on identifying all mission's actors and their expectations, thus deriving additional objectives. Once the broad objectives of the missions have been established, the following step of the design methodology is the Functional Analysis, which allows identifying the major functions to be performed for the mission's accomplishment, as well as the needed physical components. Another important analysis is related to the Concept of Operations, which has the scope of describing how the system is operated during its life-cycle phases to meet stakeholders' expectations. The overall process relies on the use of specific software tools, which provide useful means for the analyses integration giving also the chance to easily track and verify the results.

The paper reports a detailed description of the methodology, as well as an example case study in order to provide a clearer understanding of the entire process. The analyzed case refers to in-orbit validation of inflatable technology, which is one of the most significant technologies to be developed for future human space missions to deep space targets. Future human exploration programs point towards new and more challenging objectives, which require the development of new advanced systems and technologies, and their demonstration in space environment. Indeed a system is considered flight-qualified, once it has completed a demonstration mission in space environment. Accordingly, there is a great interest in the definition and analysis of dedicated missions for the in-orbit demonstration of advanced technologies.

The developed design methodology and the results obtained by applying the methodology have been obtained in the framework of STEPS-2 (Sistemi e Tecnologie per l'EsPlorazione Spaziale-Phase 2). STEPS-2 is a research project co-founded by EU on the "Misura Piattaforme Innovative"-Phase 2 of POR FESR 2007/2013.

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1. Introduction

In the last decades, there has been an increasing desire in studying and developing innovative space systems for different purposes applying new technologies [1–3]. For this reason, many recent research programs deal with the development of specific validation/demonstration missions to increase the TRL (Technology Readiness Level) of crucial technologies for space exploration [4,5]. The design of complex space missions and systems is not an easy task, and may require brainstorming and iterations to analyze several alternatives and gradually refine both the requirements and methods of achieving them.

The paper deals with the description of a versatile methodology with particular emphasis on requirements definition to support space mission design, taking specifically into account innovative technology demonstration/validation missions. The work has been developed in the framework of STEPS-2 (Sistemi e Tecnologie per l'EsPlorazione Spaziale-Phase 2). STEPS-2 is a research project co-founded by EU on the "Misura Piattaforme Innovative"-Phase 2 of POR FESR 2007/2013.

Several tools are available to support the design and specifically the definition of requirements, but no generally applicable rules or processes do exist. Design methodologies are discussed by a considerable number of authors [6–8], who consider both Functional Analysis (FA) and Concept of Operations (ConOps) as fundamental activities to capture requirements. The approach that we pursue within the present methodology specifically for requirements definition is the typical approach of Systems Engineering, which starting from the mission statement proceeds with the mission objectives through the stakeholder analysis and eventually to the definition of requirements through Functional Analysis and ConOps, as reported in [6–8]. However, unlike the design methodologies presented in [6–8], the proposed method aims at addressing how each single category of requirements (mission, functional, configuration, interface, environment, operational, logistic support, performance, design, physical and product assurance and safety) can be derived by appropriate analyses and what is generally the sequence of derived categories of requirements.

Section 2 describes the methodology, discussing the various steps that shall be performed. In Section 3, an in-depth description of the methodology is provided through the analysis of the major results for the inflatable technology case study. In particular, starting from the assessment of the mission statements and objectives, the process has gone through the Functional Analysis and Concept of Operations evaluation, with the final aim of producing a detailed and organized list of requirements.

Eventually, last section summarizes the main conclusions and proposes possible future applications of the methodology.

2. Methodology overview

Space mission analysis and design shall be regarded as an iterative and recursive process, permitting a continue refinement of requirements and constraints leading to a deeper component definition level.

Typical steps of the design process of a space mission are schematically illustrated in Fig. 1. The very first step is the definition of the mission statement. This activity shall be properly executed in order to obtain a complete, clear and concise statement that represents mission purpose for existence. This statement, as well as mission objectives, shall be fixed early because they represent mission foundation and for this reason they shall not be modified or readapted during following iterations. Primary mission objectives are directly derived from the mission statement. Simultaneously, the stakeholders' expectations shall be analyzed; this analysis mainly consists of two steps: identifying all the actors of the mission and determining stakeholders' expectations. As a consequence, secondary objectives can be derived.

Once the broad objectives of the mission have been fixed, it is necessary to proceed with the assessment of requirements. The requirements' definition is not quite an easy task, as no general rules do exist to derive them.

Two main analyses can be exploited to support the process: the Functional Analysis and the Concept of Operations (see Fig. 1).

The overall process is recursive, meaning that it shall be repeated starting from the highest level (system of systems) and going through successive lower levels (system, subsystem, …), as schematically illustrated in Fig. 2. Within this paper, the system-of-systems (SoS) and system levels are discussed in detail, in order to better highlight the recursive nature of the process.

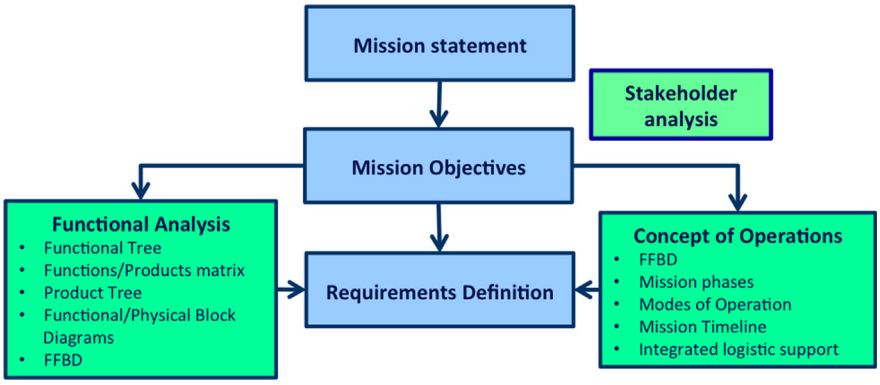

Fig. 1. General methodology overview.