X Workshop em Engenharia e Tecnologia Espaciais
7 a 9 de agosto de 2019

Towards Modeling the Concept of Operations for CubeSat-Based Missions

Almeida, D. P.[1] , Mattiello-Francisco, F.[1] , Sousa, F.L.[1]

[1]National Institute for Space Research (INPE), São José dos Campos, SP, Brasil

danilopallamin@gmail.com

Abstract. *This paper presents the on-going development of a meta-model of a CubeSat mission and its Concept of Operations (CONOPS). The expected meta-model is to-be composed by a set of artifacts contained in the Arcadia method, built inside the Capella software tool, representing a sum of viewpoints in order to serve as a central source of information within the environment of Concurrent Engineering Centers (such as INPE's CPRIME), that can benefit from an integrated system model which contains the flow of information between the disciplines present in the Concurrent Engineering approach, favoring rapid and collaborative work. In order to reach the meta-model, the author is aiming to construct a model for a case study, the NanosatC-Br2 mission. From this point, the author expects to be able to analyze and derive the generic set of steps and artifacts that other missions can reuse and instantiate, which is the meta-model.*

Keywords: CONOPS; CubeSat; Model.

1. Introduction

Due to the large advances the world has seen with component miniaturization and lower launch costs (especially with ride sharing), the development and launch of small-class satellites have seen a rise over the past couple of years. This is especially true with the nano-satellite class caused by the creation of the CubeSat standard that has been highly adopted worldwide both commercially and academically.

CubeSats are being proven to be a cost-effective solution for dedicated simple science missions, technology validation, and low-bandwidth connectivity. By being largely adopted by companies and universities around the world, the CubeSat standard provides mission designers with a wide range of reusable subsystems and components, which significantly improves spacecraft design time.

As a cost-reduction strategy, CubeSats typically are made with Commercial Off-The-Shelf (COTS) components, which commonly do not have space-grade ratings, and consequently have a lower life-expectancy and robustness. Design teams (especially in university-class missions) commonly have little experience, and it is also common to see teams skipping some Systems Engineering, AIT and V&V procedures due to schedule constraints and cost budget limitations. Along with many other possible contributing reasons, CubeSat missions have high failure rates (SWARTWOUT; JAYNE, 2016) (VENTURINI et al., 2017).

To assist developers with little experience, NASA has developed a technical report called "CubeSat 101: Basic Concepts and Processes for First-Time CubeSat Developers", to guide the developers through the main processes involved concerning CubeSat missions (INITIATIVE et al., 2017).

To shorten development cycles while reducing failure rates, it is evident there is a need to tailor SE practices and methodologies, such as Model-Based Systems Engineering (MBSE), in order to better fit and benefit from characteristics from the CubeSat standard such as platforming and reusability. Traditional approaches for large satellite development may not be suitable for CubeSats, therefore teams around the world are developing modern SE approaches for small sats such as Asundi e Fitz-Coy (2013), Waseem e Sadiq (2018) and Fischer et al. (2017).

It is important, especially in early phase studies, to have a well-defined Concept of Operations (CONOPS), which captures the users' and other stakeholders' expectations to drive the mission requirements and system design. Describing the CONOPS demands building project artifacts that represent different operational views of the system, generating a significant amount of documentation.

Centralizing design parameters, expected behaviour description, requirements and constraints within one Systems Model can improve design and system understanding among stakeholders, and even contribute to simulations as in Kaslow et al. (2014) and Spangelo et al. (2013) assisting in trade studies.

INPE's Concurrent Engineering Center (CEC) – CPRIME (*Centro de Projeto Integrado de Missões Espaciais*), has developed a satellite simulator (CHAGAS et al., 2018) which is used to simulate scenarios describing operations concepts for LEO missions. By simulating orbit propagation, power generation and consumption, and data generation and download, the simulator assists trade studies to evaluate operation modes with respect to equipment usage and downlink capabilities.

The objective of this paper is to introduce the foundation and context of the work being developed by the author, which is to develop a *model* or *meta-model* to support the process of building CONOPS for CubeSat-based missions, to be used as input for CPRIME's satellite simulator to assist in the early phase studies.

2. Methodology

A methodology can be defined as collection of related processes, methods and tools (ESTEFAN et al., 2007). This study from INCOSE defines each part as:

- A Process (P): is a logical sequence of tasks performed to achieve a particular objective. A process defines "WHAT" is to be done, without specifying "HOW" each task is performed
- A Method (M): consists of techniques for performing a task, in other words, it defines the "HOW" of each task.
- A Tool (T): is an instrument that, when applied to a particular method, can enhance the efficiency of the task; provided it is applied properly and by somebody with proper skills and training.

Associated with an Environment (E), which is all the surroundings, external objects and conditions that influence on the group or individual.

Figure 1 illustrates these elements and their relationships and effects on people and technology, edited including the chosen Method (Arcadia), Tool (Capella) and Environment (CPRIME) for the work in this project.

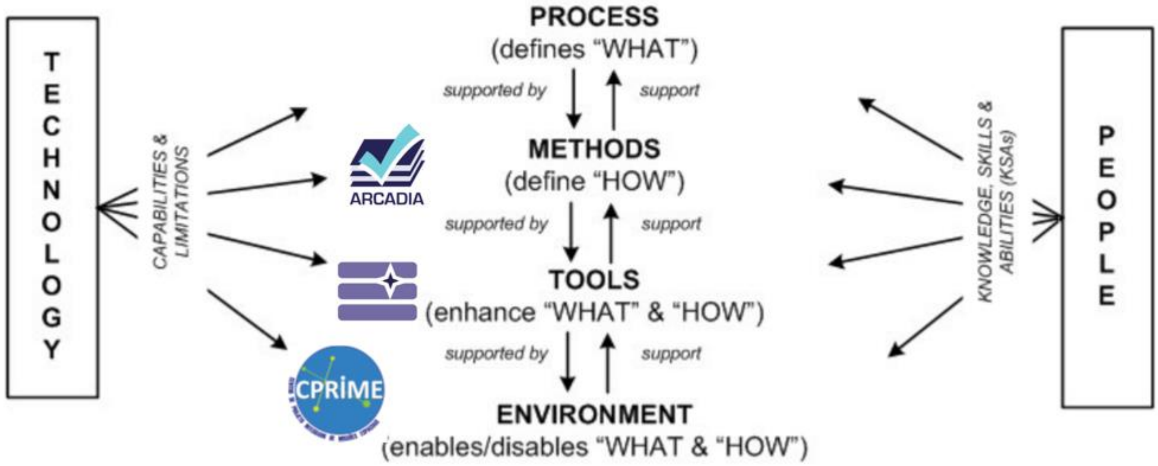

Figure 1: The PMTE Elements of the Methodology

As mentioned above, for this work the chosen method is the Arcadia method, developed at the French company Thales, which is incorporated in the open-source Capella tool, which comes with an integrated domain-specific modeling language (DSML) based on SysML, the INCOSE standard for MBSE. The integration of Arcadia and Capella, along with their DSML provides a methodological guidance in developing the model which agrees with the objective of the work to develop a meta-model for reuse. For this reason, along with being open-source and having a more intuitive and user-friendly interface (from the author's perspective), the author has chosen this method & tool.

The environment for this work considered is the Concurrent Engineering Center environment, more specifically INPE's CPRIME, driving the model to be used as input for CPRIME's satellite simulator and to facilitate information distribution among the multiple engineers and stakeholders participating in the study sessions.

The process of the methodology is exactly what is being developed, using the building blocks provided by Capella which are the Data Flow, Architecture, Scenario, Mode & State, Class and Capability Diagrams.

Representing mission CONOPS, generally one describes operation scenarios, use case implementations, data flow architecture and mission objectives. The author expects to extend the model with the systems logical and physical architectures with regards to the main subsystems, the functions and capabilities they provide, the interfaces between them, their electrical power generation/consumption, the expected data generation and download requirements.

3. Results and Discussion

In order to develop the model, the author is using as a case study, the NanosatC-BR2 (NCBR2) mission. NCBR2 is a scientific and technological mission, aiming to:

- collect data to better understand the magnetic anomaly of the southern Atlantic
- collect data to better understand the formation of plasma bubbles in the ionosphere
- validate technological components in the payloads
- develop human resources with experience in space mission development

The mission will reuse the ground segment infrastructure inherited from the NCBR program, which is a ground station at Santa Maria, providing UHF/VHF downlink and uplink capabilities, and a control center in São José dos Campos. The mission will also incorporate a new ground station at Natal, offering the same capabilities to act as a redundant channel for data download and command upload.

The spacecraft is a 2U CubeSat divided into two modules: the Bus module and the Payload module. The Bus module contains all the subsystems necessary for the operation of the spacecraft, such as: the On-Board Computer (OBC), Electrical Power Supply (EPS), Telecommunications (Transceiver + UHF/VHF Antennas), and the Attitude Determination and Control Subsystem (ADCS). The Payload module contains the three physical payloads, which are: a Langmuir Probe (SLP), a Fault-Tolerant Attitude Determination System (SDATF), and an experiment board carrying a rad-hard ASIC chip and a fault-tolerant FPGA (SMDH Payload). The two software payloads on-board the OBC are a telecommunications protocol and service for the Brazilian amateur radio community, and the attitude stabilization algorithm.

The main constraints in CubeSat missions are commonly the volume, mass, power and data budgets. In the NCBR2 mission, the mission directors decided to favor the volume in the 2U CubeSat to fit multiple payloads, having to balance the power and data budgets through operations. This is done by having operation scenarios in which the spacecraft will alternate the operation of each payload individually throughout the multiple orbits.

To model the CONOPS using Capella, the author has chosen an initial top-down approach, which begins by stating the top-level operational capabilities and functions associated with the system and main stakeholders involved in the operation. The next following steps go through the system analysis and logical architecture definition of the system, down to the physical architecture, decomposing the functions according to the abstraction level and allocating to the respective actors and components.

Figure 2 shows three example diagrams of the Operational Analysis of the model under development, showing the operational capabilities, a function dataflow expanding one of the capabilities (Validate Technological Components), and the operational architecture allocating these functions to the system and external actors. In this step, it is desired to demonstrate what the users of the system wish to accomplish.

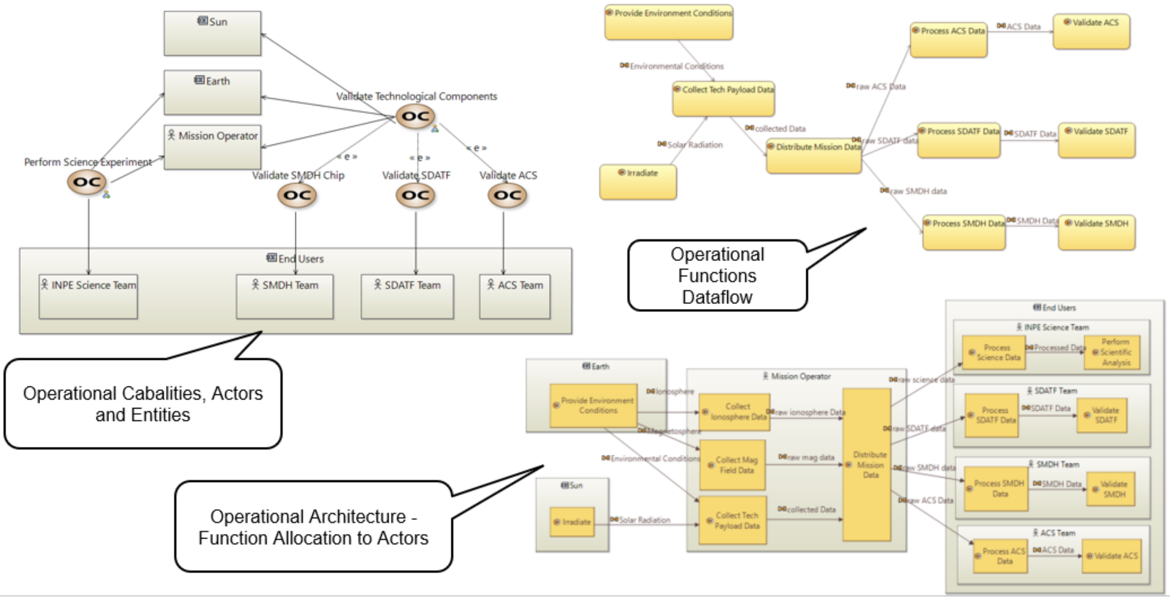

Figure 2: Operational Analysis

Figure 3 shows two diagrams of the System Analysis step, a system architecture with functions allocated to the entities and the interfaces between them, and an example function dataflow. In this step it is desired to demonstrate what the system has to accomplish for the users.

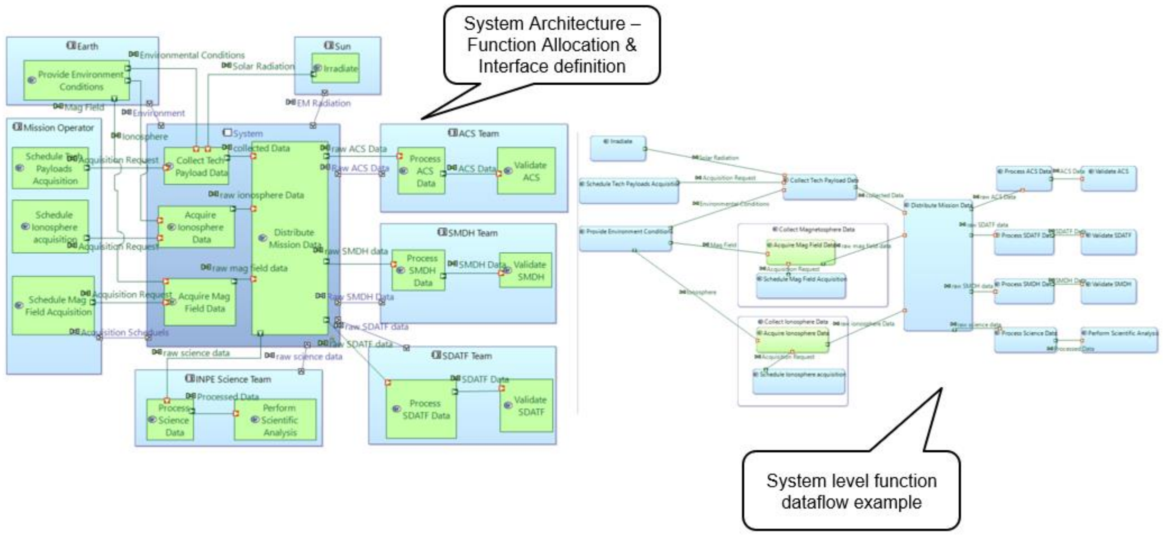

Figure 3: System Analysis

Three diagrams of the Logical Architecture step are shown in Figure 4: a function dataflow breakdown, the logical architecture with function allocation to the two main subsystems and the other actors and entities involved, and an exchange scenario diagram, which demonstrates an example of a high-level operation scenario with the sequence of functions to be realized. In this step, it is desired to demonstrate how the system will work to fulfill expectations, yet without implementation-specific solutions.

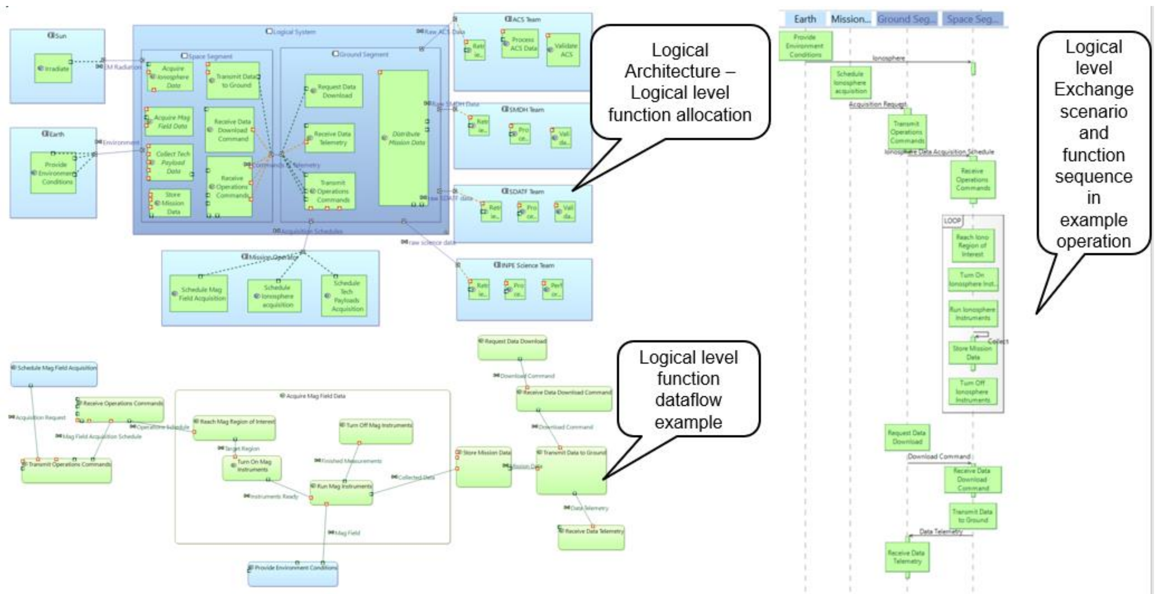

Figure 4: Logical Architecture

Figure 5 shows some functions of the lowest level of abstraction desired (still a high-level subsystem abstraction level) and an architecture diagram (still under development) which allocates these functions to the desired components. The goal of this step is to demonstrate how the system will be developed and built, with implementation-specific solutions.

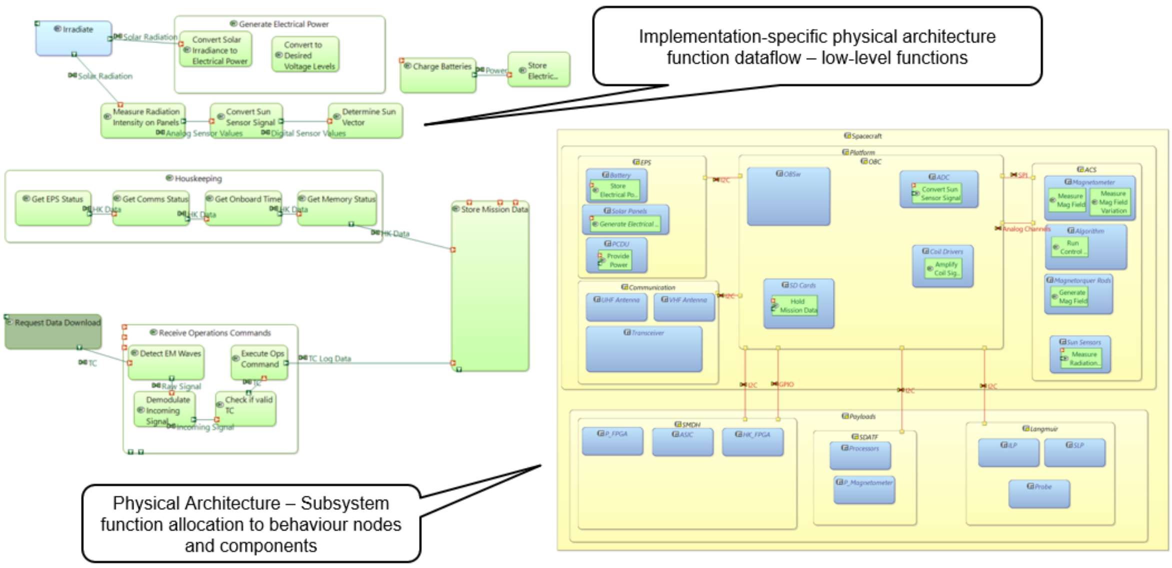

Figure 5: Physical Architecture

To achieve the desired CONOPS representation, the author expects to complete breakdown of the functions and allocate them to all subsystems and components, and then represent operation scenarios through Exchange Scenario diagrams, along with parametric modeling of the system to serve as input for CPRIME's simulator configuration script with power and data generation and usage values.

4. Conclusion

This article has shown the scope and initial results of the work being developed towards creating a meta-model of mission CONOPS for CubeSat-based missions. There is still much work to be done to reach the desired outcome, and the author has found the Arcadia method with the Capella tool to be intuitive and simple to use with the methodological guidance, which goes in line with the premises of a guided meta-model for reuse in multidisciplinary environments.

After developing the model for the NCBR2 mission, the author will derive a generic meta-model and provide guidelines for instantiation, which will be the end-product of the project.

Acknowledgements: *The author would like to acknowledge CAPES for the funding of the scholarship provided that supports this project.*

References

ASUNDI, S. A.; FITZ-COY, N. G. Cubesat mission design based on a systems engineering approach. In: IEEE. **2013 IEEE Aerospace Conference**. [S.l.], 2013. p. 1–9. 1

CHAGAS, R. A.; SOUSA, F. L. de; LOURO, A. C.; SANTOS, W. G. dos. Modeling and design of a multidisciplinary simulator of the concept of operations for space mission pre-phase a studies. **Concurrent Engineering**, SAGE Publications Sage UK: London, England, p. 1063293X18804006, 2018. 4, 29, 31

ESTEFAN, J. A. et al. Survey of model-based systems engineering (mbse) methodologies. **Incose MBSE Focus Group**, v. 25, n. 8, p. 1–12, 2007. 15, 16

FISCHER, P.; LÜDTKE, D.; LANGE, C.; ROSHANI, F.-C.; DANNEMANN, F.; GERNDT, A. Implementing model-based system engineering for the whole lifecycle of a spacecraft. **CEAS Space Journal**, Springer, v. 9, n. 3, p. 351–365, 2017. 1, 6

INITIATIVE, N. C. L. et al. **CubeSat 101: Basic Concepts and Processes for First-Time CubeSat Developers**. [S.l.: s.n.], 2017. 1

KASLOW, D.; SOREMEKUN, G.; KIM, H.; SPANGELO, S. Integrated model-based systems engineering (mbse) applied to the simulation of a cubesat mission. In: IEEE. **2014 IEEE Aerospace Conference**. [S.l.], 2014. p. 1–14. 2, 9, 29

SPANGELO, S. C.; CUTLER, J.; ANDERSON, L.; FOSSE, E.; CHENG, L.; YNTEMA, R.; BAJAJ, M.; DELP, C.; COLE, B.; SOREMEKUM, G. et al. Model based systems engineering (mbse) applied to radio aurora explorer (rax) cubesat mission operational scenarios. In: IEEE. **2013 IEEE Aerospace Conference**. [S.l.], 2013. p. 1–18. 2, 9

SWARTWOUT, M.; JAYNE, C. University-class spacecraft by the numbers: Success, failure, debris.(but mostly success.). 2016. 1, 6

VENTURINI, C. C.; BRAUN, B.; HINKLEY, D.; BERG, G. Improving mission success of cubesats. **Aerospace Corp., El Segundo, CA, USA, Aerospace Report No. TOR-2017-01689**, 2017. 1

WASEEM, M.; SADIQ, M. U. Application of model-based systems engineering in small satellite conceptual design-a sysml approach. **IEEE Aerospace and Electronic Systems Magazine**, IEEE, v. 33, n. 4, p. 24–34, 2018. 1, 6, 16, 31