Pico and nanosatellite system architecture development process

Lucas Lopes Costa, Geilson Loureiro, Eduardo Escobar Burger, José Sérgio de Almeida

National Institute for Space Research (INPE)
Av. dos Astronautas 1758, São José dos Campos - SP, Brazil
Phone: +55123208 7022, Mail: lucas.costa@inpe.br

Abstract: The amount of pico and nanosatellites space missions has sharply increased since the platforms standardization and the growth of launch opportunities. Pico and nanosatellites projects arise as a new branch in the domain of spacecraft programs. The traditional engineering development process and practices may not be fully appropriate on small spacecraft. The absence of a tailored development process for such class made many projects to be developed without establishing engineering practices due time consuming for this activity. A new set of practices and engineering approaches are needed to achieve appropriate schedule, budget, quality and risk management to develop a balanced solution that satisfies stakeholders needs for the pico/nanosatellite class. This paper objective is to present a pico/nanosatellite system architecture reference process. The suggested process conciliate the simplicity need, low cost, reduced schedule and the participants little experience with the results and essential system engineering activities for a satellite development. The paper presents the process scope as well as its micro activities components through the thinking strategy to be used for each activity development, suggested tolls and their individual output. The paper also presents the suggested process application for the Brazilian CubeSat project AESP-14, showing the difficulties and lessons learned.

1. Introduction

The amount of pico and nanosatellites space missions has sharply increased since the platforms standardization and the growth of launch opportunities. The number of CubeSats launched in orbit has grown exponentially since 2002 (Zea et al., 2016).

Pico and nanosatellites projects are a breakthrough in the space domain and became a success mainly due the commercial off-the-shelf (COTS) equipment and components that allows fast development time and the commercially frequently available launch opportunities (Virgili-Llop et al., 2016).

The traditional engineering development process (e.g. NASA, ESA, DoD, INCOSE) and its practices applied for such a small satellite may be overdone and may not be suitable for the pico and nanosatellites project development.

The absence of evidence that applying a traditional engineering approach to a pico or nano-satellite development is successful and the unavailability of a tailored process made many projects choose to be developed without establishing engineering practices due time consuming for this activity. A new set of practices and engineering approaches is needed to achieve appropriate schedule, budget, quality and risk management to develop a balanced solution that satisfy stakeholders needs for this satellite class.

This paper presents a tailored SE process for pico and nanosatellite architecture development and the results and lessons learned from its application for the Brazilian pico-satellite project AESP-14.

2. Systems Engineering at Small Satellite Projects

Systems Engineering (SE) should be reminded as an engineering development philosophy that can be used for any development (product, process or organization). To see from a holistic and system point of view is not easy and even more difficult is for people trained as components engineers. SE education is often seen as an extension to the regular engineering courses and undergraduate university programs in systems engineering are rare (Muller, 2005).

Professionals who were trained to solve and develop specific problems (traditional courses) often need long time training and studying to see from a systems view. The thinking approach is due the functional, risk, stakeholders and architecture concerns that must be considered during all the development in parallel to design and performance goals.

"Systems engineering is a multidisciplinary and collaborative engineering approach to derive, develop and verify a balanced solution along its life cycle and attend stakeholders expectations" (Loureiro, 1999).

"Systems engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem: operations, cost and schedule, performance, training and support, test, manufacturing, and disposal. SE considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs" (INCOSE, 2011).

As the definitions say, the multidisciplinary approach is needed to develop complex systems. For pico/nano-satellite projects the understanding and application of a SE process must be part of the development due its importance to have a balanced solution avoiding re-work, schedule overruns, lowering costs, and even reducing system complexity in several projects.

The definition of a SE process is usually done through traditional space SE processes tailoring (e.g. NASA, ESA, DoD). The SE processes tailoring effort for pico/nano-satellites must change the process structure so that activities are clustered and adapted getting new labels or even excluded to the point that the tailored process gets ideally wrought for such application.

The tailored SE process must consider the specific characteristic of each project, as example: the development environment, team technical experience and knowledge in addition to the organization culture and internal process. Larson (2009) says we need to agree in a common system engineering understanding in such way that, no matter how roles and responsibilities are distributed we need to be sure it will be developed in a clear and objective way as an unit functionality.

3. Pico and Nanosatellite Architecture Development Process

The SE activities can be internally divided in groups according its goals or functions. These functional divisions have no standard and each organization or project uses a different one that best fits and forms the basis for process development. The Figure 1 shows the functional division for the SE activities used to develop the process shown in this work.

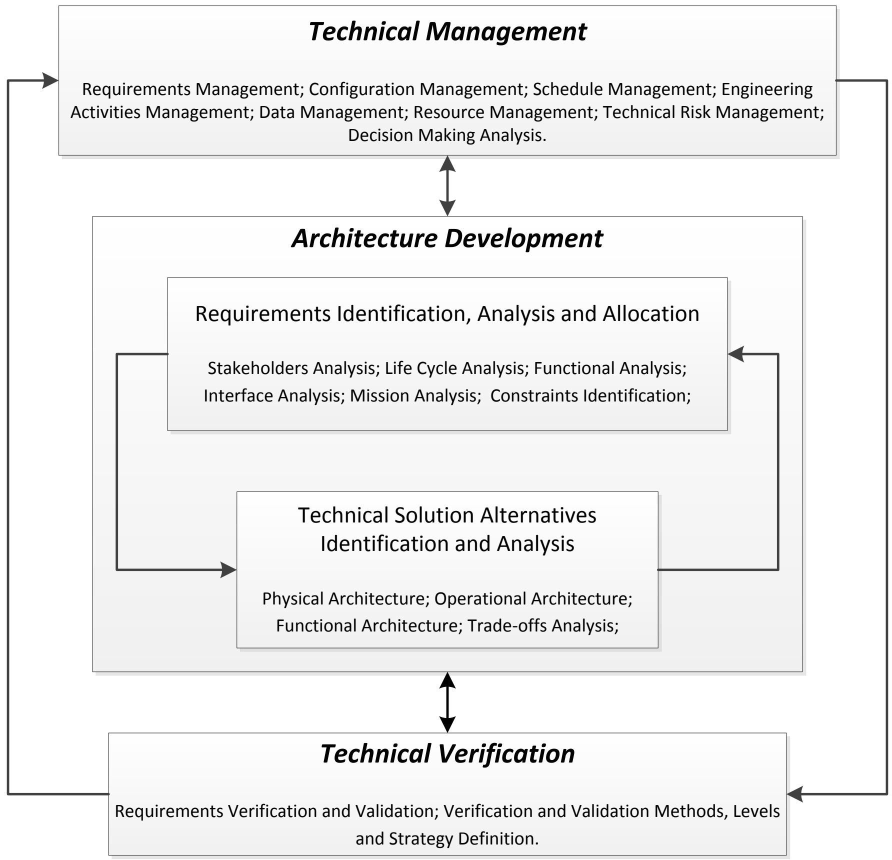

Figure 1. Example of System Engineering Functions for a pico/Nano-satellite Project.

The technical management consists of the project technical integration effort with the objective to comply the schedule, costs and requirements management. The SE process planning and control is the main activity of technical management to obtain an optimal technical solution to the system. The following elements form the Technical Management function:

- Requirements management
- Configuration management
- Schedule management
- Technical activities management
- Documentation management
- Resources management
- Technical risks management
- Decision making analysis

The Architecture Development (AD) function consists in the effort of identifying stakeholders' needs, translate stakeholder needs into technical requirements, develop and design balanced alternatives solutions to comply with the requirements. The AD function is composed of two activities blocks:

- Requirements identification, analysis and allocation
- Technical solution development and analysis

The Technical Verification consists in the effort of verification methods planning, definition and execution, requirements verification levels definition and model philosophy. The following elements forms the Technical Verification function:

- Requirements verification and validation
- Verification and validation methods definition, levels and strategies

The functional division of the SE activities is essential for a pico/nano-satellite development mainly when many students are involved and more than one Systems Engineer exists. The example shown at Figure 1 allows the activities division into three high level work packages and its sub-packages besides the definition of the interfaces and iteration between the blocks.

The Figure 2 shows the global view of the AD process for pico/nano-satellites objective of this paper. Some points related to the process model are highlighted:

- The AD process comprises Mission Analysis, Life Cycle Analysis, Stakeholder Analysis, Functional Analysis and Implementation Analysis. These processes consider, from the outset, the product not only in its operations context but also in all other life cycle process scenarios contexts for all analyses performed (approach extracted from Loureiro, 1999).
- The AD process differs from traditional space projects AD due to the different phasing structure adopted for pico/nano-satellite projects.
- The AD process considers the analysis with the main life cycle scenarios early in the conceptual study phase of the system. This approach allows the identification of elements to be developed and processes that the pico/nano-satellite must be submitted.
- The AD process foresee the development of few documents, making easier the configuration and documentation management.
- The AD process activities are free for modeling and tolls.
- The AD process simplifies traditional ones, without losing the results and core activities objective.
- The AD process considers two hierarchy levels, beginning for the mission level (space mission architecture) and converging along the same process to the development of a specific segment (e.g.: space segment). It is possible to note that activities are repeated for different hierarchy levels, but with different thinking approaches.
- The AD process is highly iterative and non-linear.

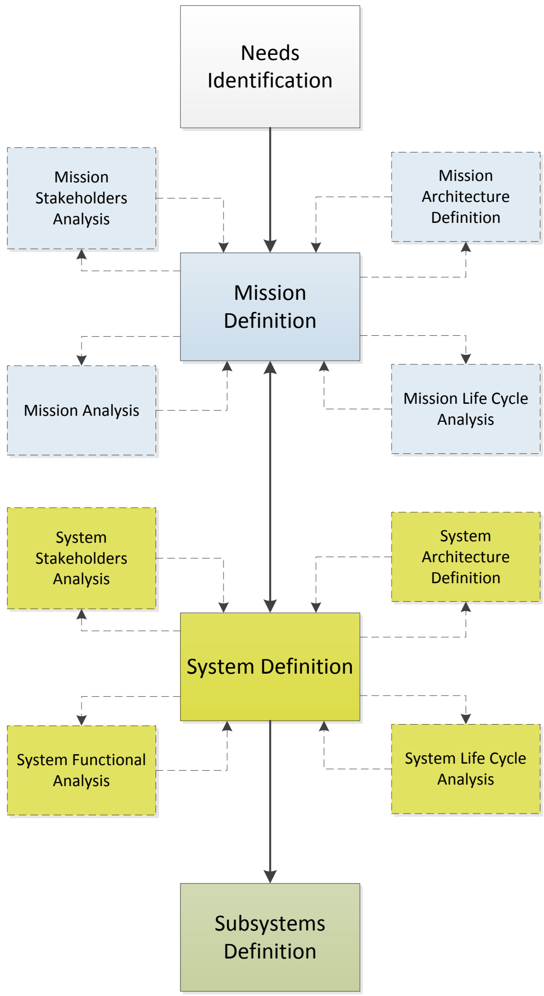

Figure 2. Pico/Nano-satellite Architecture Development Process.

The pico/nano-satellite AD process main activities blocks and respective sub-activities are:

- Needs Identification: identify stakeholders needs and define top level mission requirements.
- Mission Definition: define the mission operational concept, mission requirements and mission architecture elements requirements.
- System Definition: define the system of interest requirements (segment to be developed), identify technical alternatives solutions to the system of interest, decompose the system requirements into its parts (lower hierarchy level) and define the physical solution, functional architecture and its relationship.
- Subsystems Development: Define the requirement to the lower hierarchy level to be developed by specialists of each knowledge area (e.g: power subsystem developed by electrical/electronic engineer).

Figure 3 shows the AD main activities block diagram defining its inputs and outputs. The Subsystems Definition activity is not shown due specific specialist process development. Detailed sub-activities and more information about the process are defined at reference [1].

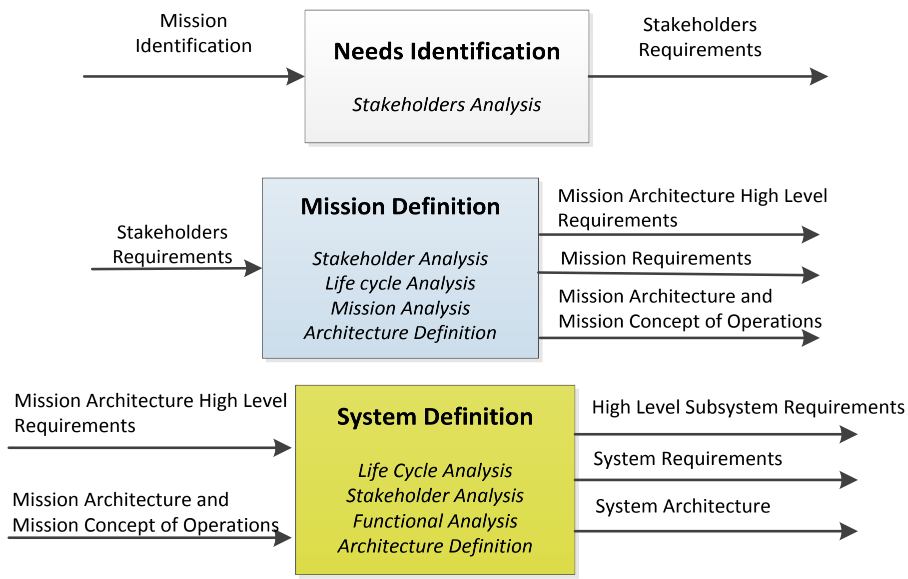

Figure 3. Pico/Nano-satellite Architecture Development Process Activities block diagram.

The AD process framework presented shall be integrated and developed in parallel with the other SE functions (Technical Management and Technical Verification) to form the total SE process. The overall SE process shall be tailored for each project application in the way to achieve the objectives of developing an optimal solution to the system of interest.

4.The Architecture Development Process Application – AESP-14

The AESP-14 satellite is Brazilian 1U CubeSat developed in cooperation between Technological Institute of Aeronautics (ITA) and National Institute for Space Research (INPE) conceived in 2012. The main missions of AESP-14 were education and training of students from both institutions by developing a real space mission.

The Architecture Development Process presented in this paper was tailored with the experience obtained during the development of the AESP-14 CubeSat. Figure 4 shows the tailored AD process used for the AESP-14 project.

In Figure 4 it's possible to note that the technical development process used was tailored according the specific needs of AESP-14 Project. The main modification is related with the parallel development of the hardware architecture and mission development. This approach was performed due one of the AESP-14 goals of developing a multi-mission CubeSat platform (service module). The platform development was supported due a partnership between AESP-14 team and another CubeSat project developer team, the NANOSATC-BR that used a commercial standard CubeSat platform.

The multi-mission CubeSat platform architecture was used for the AESP-14 mission and the parallel development enabled the fitting of AESP-14 system requirements to the platform in a smooth way. The final junction of the parallel development is the activity AESP-14 System Architecture Definition were the requirements allocation from the system requirements (derived from AESP-14 mission definition) to the physical platform architecture were performed followed by Detailed Subsystems Development.

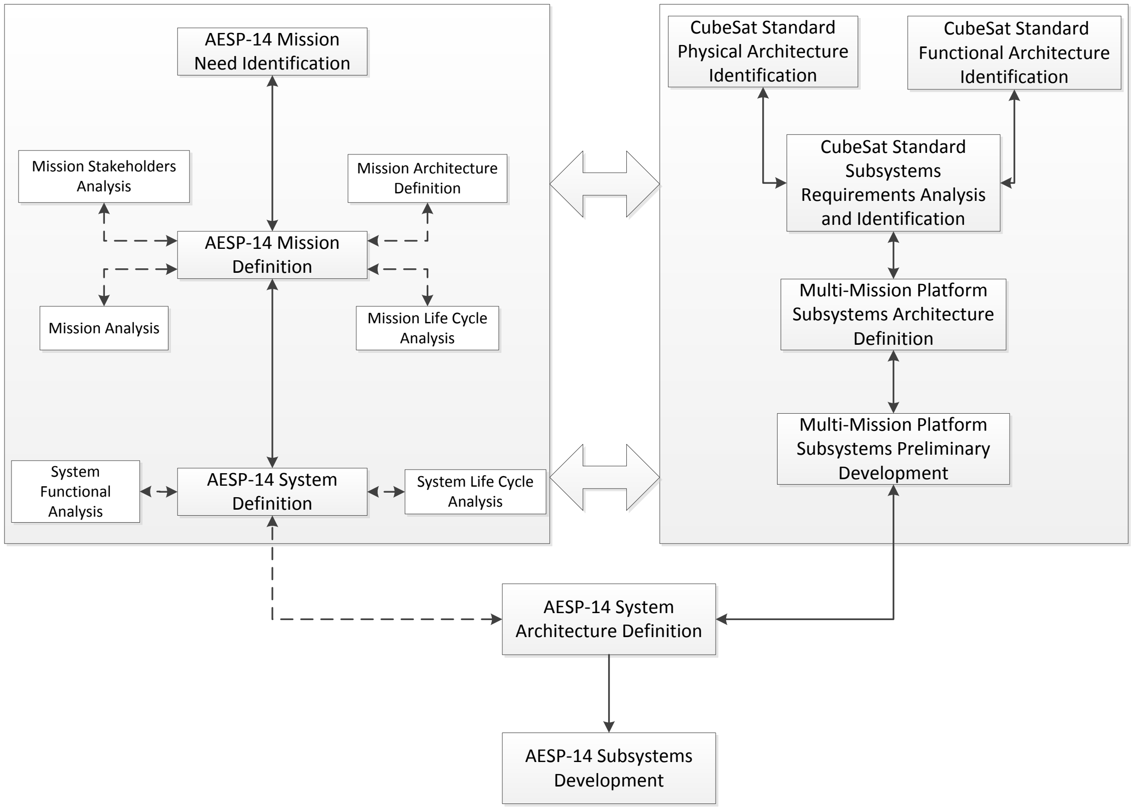

Figure 4. Architecture Process Development of AESP-14 satellite.

5.Results and Conclusion

The AD process application for the AESP-14 satellite development was conducted by the core project team with participation of undergraduate students from ITA under the supervision and collaboration of INPE engineers. The AD process application resulted in the following AESP-14 project documents:

- Stakeholder Analysis and Mission Requirements
- Mission Analysis
- Mission Operational Architecture Description
- System Requirements
- System and Subsystem Requirements
- Systems Engineering Plan

The following aspects are considered lessons learned with the application of the AD process:

- The SE process (including AD process) tailoring shall perform the enough activities and tools application for each development. The inexperience can lead to exaggerate in activities and analysis realization resulting in schedule overruns.
- The AD process application allowed a system view perspective of all project participants and to perform actions to mitigate or avoid possible future problems.
- The use of visual tools and methods is important to fast and effective technical information common understanding.
- The system and holistic view is a thinking philosophy which is only completely

understood with practice and experience.

- Scientific or Technological payloads for pico/nano-satellites with education purpose shall be in advanced technical maturity.
- The work package deployment and activities responsibility definition is fundamental during project development.
- The constant re-work and modifications during small activities are important for the team knowledge and experience gain and also for SE process tailoring discussions.

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