The ITA Space Center and its role in space education in Brazil

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ABSTRACT

This paper presents the ITA Space Center and its mission in the formation of human resources and in the research and development of space products. In 2012 the first aerospace engineers were graduated at ITA, and since then many efforts have been done to improve the engineering education. The first effort was the development of AESP-14 CubeSat project, then the development and launch of ITASAT, a 6U CubeSat. These two projects showed that small satellites projects provide a good learning approach once students were deeply involved in the development process. These two projects opened the opportunity for the creation of the ITA Space Center (CEI - acronym for *Centro Espacial ITA in Portuguese*). Inside its facilities the ITA Space Center provides capabilities for the development of small space projects such as electronics, software engineering, mechanical design, and simulation with the aid of systems engineering and project management. By means of the graduate and undergraduate programs the ITA Space Center is providing education and integration with the industries and other partner organizations. In developing and delivering space products, and fostering higher education in space, the ITA Space Center is accomplishing of its proposed mission.

INTRODUCTION

On January 28th, 2020, ITA inaugurated the ITA Space Center - CEI at a new building facility in the school Campus. With 277 m2, CEI is providing means to transform the education on space systems engineering through hands-on training and in-orbit CubeSat operation. CEI offers tools and methodologies for concept, analyze, simulate and engineering space products life cycle.

Figure 1 illustrates the ITA Campus side where the ITA Space Center is located.

Figure 1 - ITA campus illustration pointing the location of the ITA Space Center.

The Brazilian Air Force's Strategic Program of Space Systems (*PESE – Programa Estratégico de Sistemas Espaciais*) defined the Aeronautics Institute of Technology (ITA) as the academic central institution responsible for educating engineering students for the military as well as civilian institutions, including undergrad and graduate courses. So, to allow the training in the space systems life cycle and covering the Space Related disciplines, the ITA Space Center is constructing a set of laboratories.

CEI adopted Project Based Learning (PBL) to provide the hands-on learning experience through a project-based education[1]. Through this approach, CEI associated professors train and prepare the undergraduate and graduate students on Space Systems activities. At CEI students have the opportunity to work in real projects that enhance their abilities to solve space related problems. This problem-based learning leverages the working group capacity to organize their tasks and apply balanced solutions fostering the communication among the team.

The Concept - Design - Implement - Operate (CDIO) approach, is the fundamental base for the students to obtain knowledge that will be used in their space systems engineering careers[2]. The CDIO approach allows students to learn how their activities impact the system life cycle collaborating in whole project phases. The students gain knowledge and skills by working in the investigation, analysis and simulation of the complex questions that are inherent to the space products development.

This approach provides critical thinking, communication, creativity, and responsibility to the students. Also, this approach provides the feedback in the learning process, where it can be stated during the project reviews when the students present their finds and results. The undergraduate and graduate courses have an industry-university program that benefits the industry sector by the projects the students develop during their academic years. With this win-win collaboration it is possible to accelerate the insertion of human resources in specialized jobs positions after graduation.

AESP-14

The first CubeSat project developed at ITA was the mission called AESP-14 (Figure 2), a 1U CubeSat developed in the context of the Aerospace Engineering Course[3]. During the graduation course students were invited to participate in the development of the CubeSat. Aided by mastering students, the satellite was developed, integrated, tested, and launched on January 10th, 2015. The mission of AESP-14 was to develop a platform in house and engage students.

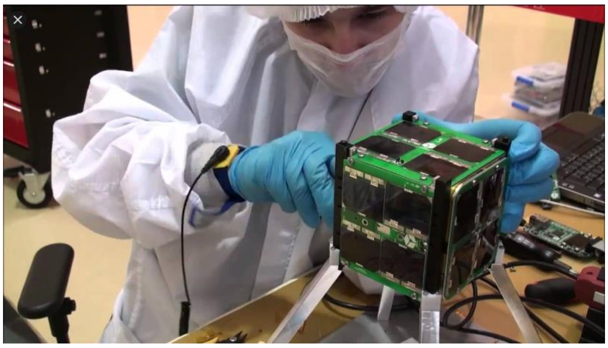

Figure 2: AESP-14 Integration Campaign.

ITASAT-1

ITASAT-1 was first proposed as an 80kg educational satellite, and in 2014 it was reviewed as a 6U CubeSat[4]. The objective of this mission was to train human resources in space related projects and the scope was to develop a platform to perform payloads tests on orbit. Developing a CubeSat was a challenge at ITA, specially to involve undergrad students and graduated students. To make this possible, the ITASAT team was composed of students and former industry experts. In 2016 the satellite was fully integrated, tested, and ready to launch, but due to launching opportunities issues, it was launched on December 3rd, 2018. Since then the telemetries of ITASAT have been received showing that the platform is behaving stable. Figure 3 shows the Engineering Model of the ITASAT being tested at the former CEI facility.

By means of ITASAT, ITA was able to deliver to industry, research institutes and universities space skilled human resources. Former ITASAT participants are working in space related industries in Brazil and abroad, some of them are running their own companies in the space sector.

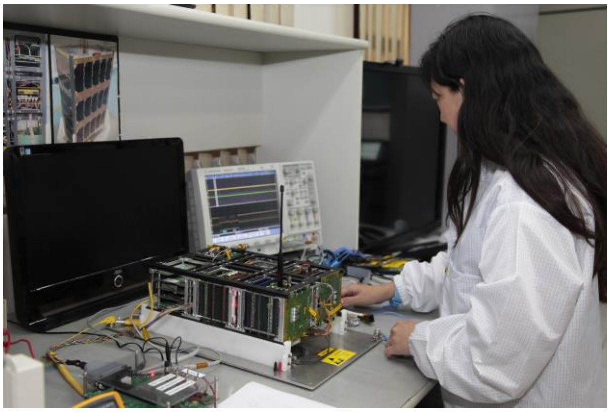

Figure 3: ITASAT-1 Engineering Model being tested.

There are also ITASAT former participants at research institutes, such as at the National Institute of Space Research INPE (*Instituto Nacional de Pesquisas Espaciais*). At Universities former ITASAT participants are acting as well, teaching in State Universities, Federal Universities and Private Universities. There is a former ITASAT participant working as a professor at the Computer Department at ITA.

ITASAT played an important role in the context of ITA Space Center consolidation, once it showed that it is possible to involve students in a real activity to design, assembly, integrate and test a space system. Part of the developing group of ITASAT is still at ITA Space Center grabbing new technologies, methodologies and aiding the students to be involved in real projects.

SPORT

With ITASAT ready for launch, ITA proposed together with national and international partners the SPORT mission [5,6]. SPORT is a 6U CubeSat mission for space weather monitoring. The role at ITA in this project is to develop the observatory platform and integrate and test the science instruments. Figure 4 shows the SPORT 3D Printed Mockup shown during the CDR (Critical Design Review) in August of 2019.

Besides the engineering challenges to develop a space project, it is necessary to come back to the main assignment of ITA, which is to provide high level education in Brazil. Students are invited to join the SPORT project and in a hands-on way, improve their knowledge and motivate them to find new paths to do engineering and science.

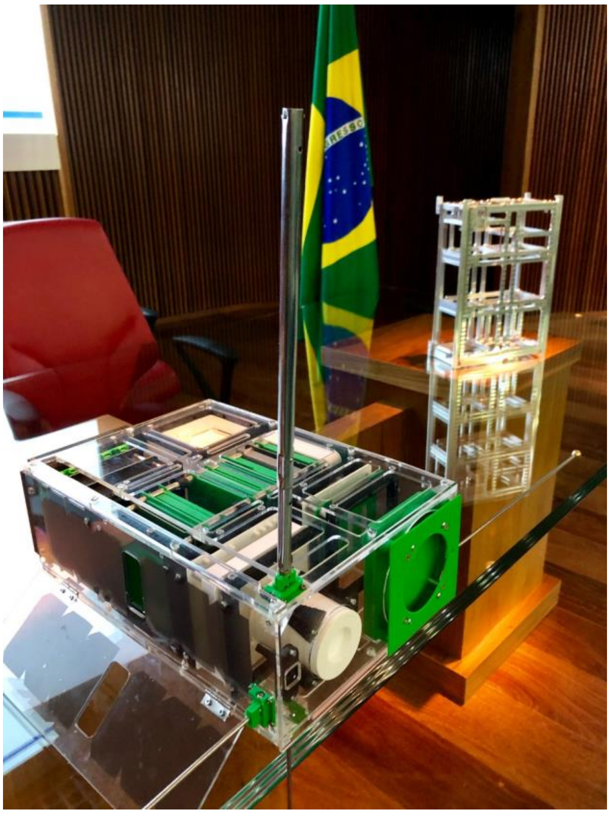

Figure 4: SPORT Mockup at CDR.

Because of that, SPORT CubeSat has been used as a case study or example of application during Aerospace Engineering courses at ITA, as well as in undergraduate final reports, master, and doctorate thesis.

Undergrad / Grad Context

The ITA Space Center is part of the Aeronautics & Aerospace Division Laboratories, as the (i) Aerospace Structural Laboratory, (ii) Aeronautics Engineering Laboratory, (iii) Computational Laboratory, (iv) Energy, Combustion and Propulsion Laboratory, (v) Rocket Technology Laboratory, (vi) Liquid Propulsion Laboratory, (vii) New Concepts in Aeronautics Laboratory, (viii) Advanced Computational Aerodynamics Simulation Laboratory and the (ix) Flight Simulation Lab.

All those labs collaborate into the Aerospace undergraduate course, as well as in two graduation courses.

The Aerospace undergraduate course aims to provide a strong academic background to the alumni personnel. The course covers the major topics related to space missions, space systems analysis, and related disciplines. It covers the research, design, development, construction, testing science and technology of space systems. The course has a five-year program, the first two years are the basic engineering subjects, the later three years are the professional subjects.

The two graduation courses ITA hosts are related to Science and Space Technologies, and Aeronautical and Mechanical Engineering.

CEI

The construction of CEI was divided in two phases (depicted in Figure 5). The first phase contains laboratories regarding the descent side of the Vee Model [7], hosting Conceptual Studies and Development. The laboratories are the: (i) Integrated Project Management Room (SIGP, in Portuguese it stands for *Sala Integrada de Gestão de Projeto*); (ii) Aerospace Systems Simulation Laboratory (LSSA, in Portuguese it stands for *Laboratório de Simulação de Sistemas Aeroespaciais*); (iii) Space Systems Laboratory (LSE, in Portuguese it stands for *Laboratório de Sistemas Espaciais*); and the (iv) Aerospace Systems Tests Laboratory (LTSA, in Portuguese it stands for *Laboratório de Testes de Sistemas Aeroespaciais*).

A second phase will complete the rising part of the Vee, with laboratories related to AIT (Assembly, Integration and Test) activities, as the Aerospace Systems Integration Lab (LISA, in Portuguese it stands for *Laboratório de Integração de Sistemas Aeroespaciais*) and the Satellite Operation and Control Laboratory (LCOS, in Portuguese it stands for *Laboratório de Controle e Operação de Satélites*).

The first phase was built into the Fundamental Courses Building of ITA, into a 277m2. The laboratory distribution is illustrated by the Sketch in Figure 6.

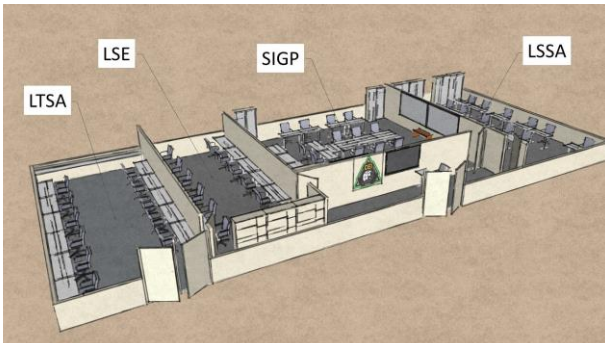

Figure 6: Laboratories distribution.

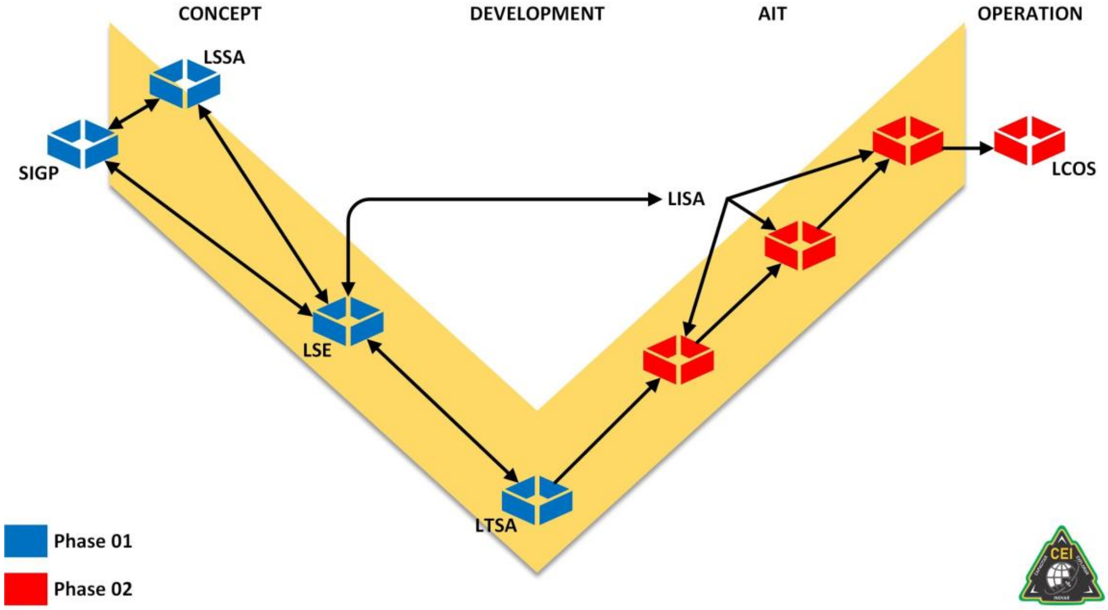

Figure 5: CEI laboratories distributed in the Vee Model.

Concept Studies

In Phases Pre-A to Late A, prior to MDR, conceptual studies are done to mature the stakeholder concepts, mission viability, alternatives of mission and systems' architectures and requirements. In this context, a common approach is to perform Concurrent Engineering to build-up concepts and architecture and simulate to validate, so a more concise requirement is written.

SIGP was designed to exercise Concurrent Engineering[8]. The collaborative approach, in an Agile Environment, allows the concepts, architectures and requirements writing to evolve faster and transdisciplinary[9]. Concurrent engineering is traditionally based in 5 domains: (i) Teams: the specialists that creatively create the products; (ii) Facility: the local that hosts the team, and is designed to improve the human-to-human collaboration; (iii) Integrated Design Model (IDM): the "single source of truth" model that integrate the team specialist points of view; (iv) Tools: the resources that are used by the specialists to create the products; and (v) Process: the framework of steps that are organized to evolve the study.

Figure 7 contains a photo of the SIGP, with the table distribution in U to host specialists and central tables to host stakeholders. Besides the table, the lab also has two independent projects, that are wirelessly connectable by all the room's computers, and a side 80" monitor to display schedule and study steps information. Whiteboards/Flipcharts, fixed and on rolling tripods, also allows groups to clusterized the talks and discussions.

The SIGP can run Concurrent Engineering based in Office Tools as well as Model Based Systems Engineering Tools, as OPM and Arcadia [10,11]. The room itself is a tool to Systems Engineering. The capability to change the layout allows the facility to adapt to different study domains and strategies. Although the CEI was designed for Space Engineering, a Concurrent Engineering Facility can easily serve other studies.

Figure 7: SIGP Photograph.

The SIGP hosts undergrad and graduate students interested in the Systems Engineering and Concurrent Engineering research, as well as a framework to evolve their own alumni initiatives - as the ITA's Rocket Design. Systems Engineering, Project Management and Concept Studies subjects benefits of this lab to teach and demonstrate the engineering collaboration processes.

LSSA was designed as a mission and systems simulation hub. Through integrated simulation scenarios, the concepts and architectures can be evaluated, requiring design reviews, or validating to move to next steps/phases. Modelling and Simulation allows the concepts and architectures to be timely verified, as their dynamics interact through-out the modelled lifecycle in faster simulated time. Multiple scenarios can be created to test the architecture resilience and run in parallel.

Figure 8 contains a photo of the LSSA. The LSSA has a classroom table organization. In the front, a two coupled project creates a double screen, and is extended by one 80” monitor at each side. This organization implements a Powerwall that enables semi-immersive simulations.

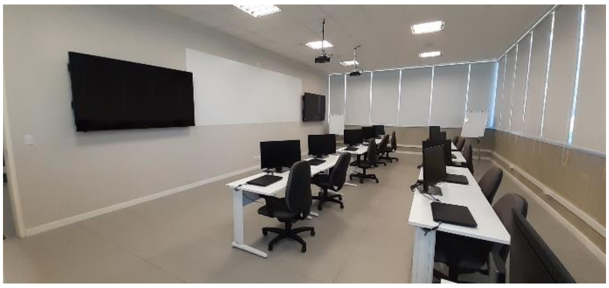

Figure 8: LSSA Photograph.

The LSSA can run 10 standalone or arrangements of distributed simulations. The laboratory uses STK®, Matlab®, Modelica® and other systemic simulations tooling, both commercial and in-house developments. A 32Gb RAM, Intel i7 Server, with an AMD FirePro W9100 video card, renders the simulations to project into the Powerwall.

The LSSA hosts undergraduate and graduate students interested in systems simulation, spacecraft and space mission simulations, budgets, and distributed space systems. Alumni initiatives, such as the CanSat and CubeSat development to the INPE’s CubeDesign Competition can use the laboratory to simulate the competition scenarios that their design will experience. Design and Construction of Aerospace Systems and Concept Studies benefits of this lab to teach and demonstrate simulations.

Development

Phases B and C, usually covering the prototypes, the Engineering Model development, the Systems Engineering and programmatic issues. The logical architectures are concretized into physical architectures or instantiated architectures. Budgets must be applied and monitored, as well as cost, schedule, and risks. Engineering Specialties develop their domains, requiring a project management, integration, as well as a continuous verification and validation process to ensure that requirements and the stakeholder expectations are met.

LSE has a heritage design from previous CEI locations. All the follow-up disciplines that monitor the mission collaborate to track each domain, as: (i) Systems Engineering, handling requirements, architecture changes and budgets; (ii) Procurements, handling costs, lead times and acquisitions; (iii) Risk, handling risk tracking and mitigations; (iv) Schedule, handling master schedules and subsystem schedules; (v) Quality Assurance, handling the processes and controlling configurations; and (vi) Verification and Validation, handling the processes, reviews and V&V activities.

Figure 9 contains a photo of the LSE. The LSE has an open floor plan concept. The laboratory hosts the software and tools to the following disciplines. Figure 9 also shows a 3D Printer, which is currently hosted in the lab.

If a Phase B to C mission is running in the CEI, the students will hold one of the follow-up disciplines. The laboratory can track its own mission or supporting alumni initiatives. As an example, ITA’s Rocket Design team seeks CEI to incorporate V&V and design reviews into their development lifecycle.

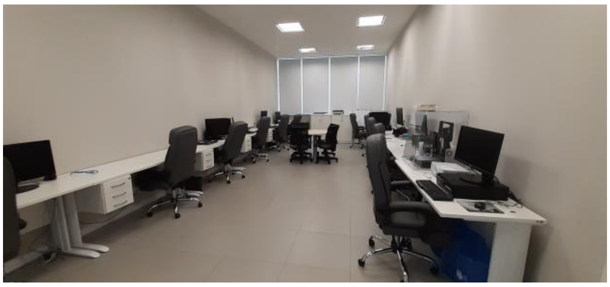

Figure 9: LSSA Photograph.

The LSE mostly hosts graduate students interested in the follow-up disciplines. It is suggested that the dissertations and thesis are tied with the running project to provide the real cases. LSE provides a more systemic experience to the undergraduate alumni and usually a source of subjects to their final graduation work.

LTSA also has a heritage design from previews CEI locations. It hosts the Engineering Specialties, as: Mechanical, Thermal, Electronics, Control, Telecommunication and Software. Each discipline creates their own prototypes and series of FlatSats to integrate and test the evolution of the domains.

Figure 10 contains a photo of the LTSA. The LTSA has an open floor plan concept. The laboratory hosts the software and tools for each discipline. The left tables host all the software domains, as the EGSE (Electrical Ground Support Equipment) software, the attitude control software, the onboard computer operating system architecture and the payload drivers and emulation software. On the left side, the FlatSat is placed to test the onboard software and the peripheral control. The right tables host the electronic, telecommunications and mechanical domains. At the back, two assembly tables to perform mechanical integration and electronic integration of the prototypes and Engineering Model. In the future the laboratory will also host a clean room tent to assembly protoflight models.

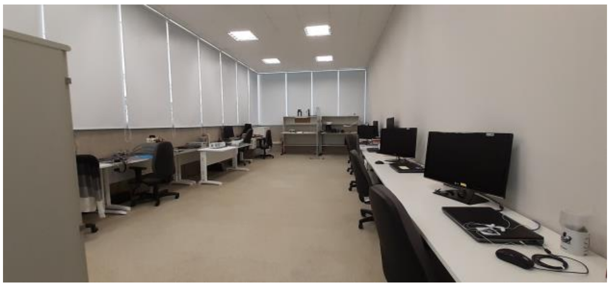

Figure 10: LTSA Photograph.

In the LTSA, the product disciplines receive their requirements and constraints, so the students will be requested to provide each domain solution. The laboratory uses state of the art tools such as Thermal Desktop®, Altium®, LabView®, SolidWorks® and the coding IDEs that each onboard computer supplier suggests. The laboratory also has the soldering and mechanical tools to assembly PCBs (Printed Circuit Board), structures and harness.

The LTSA mostly hosts graduate students interested in how the product disciplines interact to create Space Systems. It is also suggested that their dissertations and thesis are tied with the running project to provide the real cases. LTSA provides a more in-depth experience to the undergraduate and graduate alumni, as they will work more into the disciplines fields that will interact to provide the emergence properties defined by the systemic view. The Verification and Quality of Aerospace Systems subjects benefits of this lab to demonstrate how the V&V is handled. As ITA also hosts Computer, Mechanical and Electronic Engineering, the LTSA is an applied space intersection with their domains.

FUTURE INFRASTRUCTURES

Phase 2 of the CEI will implement the rising side of the Vee Model, from Phase D to F. The two facilities that are envisioned are being designed to provide integration and environmental testing and to operations.

The LISA proposed design will host the transition from the LTSA products to the AIT campaigns. The expectation is that the laboratory will host mechanical and electrical functional verification tools; environmental testing equipment as vacuum chambers, thermal chambers, and vibration testing systems; mass properties and shipping preparation.

The LISA expectations are to host students' interest in the AIT equipment and its processes, so they can improve the tools and how the processes are handled and tailored to different types of systems. The Verification and Quality of Aerospace Systems subjects will benefit from this lab to teach and demonstrate how the V&V and AIT is handled. Student initiative will also benefit of this lab, to assemble, integrate and test their systems.

The LCOS proposed design will host the Space Segment Systems operations. The expectation is that the laboratory will allow the students, via simulations or via real spacecrafts, learn how to operate and control spacecrafts. They will learn how to create mission plans, unfold in passage plans, send telecommands, receive telemetries, and process mission data.

The LCOS expectations is to host students interested in the operation phase, the equipment required, the software and its processes. The students will mostly research ways to improve the current approaches, automations, and tailored ways to operate space systems.

FINAL CONSIDERATIONS

All those capabilities and activities described above performed through the CEI are creating a new and strong competence for students and professors in Space Systems Engineering. Students are getting educational training on the practices at the CEI due the hands-on and project-based learning. Professors are performing research and applying techniques for space related problems and teaching their learning to the new space enthusiasts' generation. While students and professors are leveraging their knowledge and sharing their learning, one of the main purposes of the CEI are achieved: impact the Brazilian space education through specialized human resources. The benefit for the Brazilian Air Force and other institutes are achieved due the analysis and activities that are multidisciplinary conducted at CEI. Activities related to the systems engineering tasks, mission analysis, and requirements generation have been conducted through Model-Based Systems Engineering. At ITA, the CEI is accomplishing its goals and playing a very important role in the space education scenario in Brazil.

Acknowledgments

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References

1. Thomas, J.W., A review of research on project-based learning. The Autodesk Foundation, California, 2000.
2. Crawley, E.F. et al., Rethink Engineering Education: The CDIO Approach, Springer, 2014.
3. Bürguer, E.E et al., "Development and analysis of a brazilian cubesat structure," Proceedings of the 22nd International Congress of Mechanical Engineering, Ribeirão Preto, SP, November 2013.
4. Sato, L.H.S et al., "The ITASAT –The Lessons Learned from the Mission Concept to the Operation," Proceedings of the 33rd Annual AIAA/USU Conference on Small Satellites, Logan, UT, 2019.
5. Spann, J. et al., "The Scintillation Prediction Observations Research Task (SPORT): An International Science Mission using a CubeSat," Proceedings of the 31st Annual AIAA/USU Conference on Small Satellites, Logan, UT, 2017.
6. Loures da Costa, L.E.V. et al., "The Scintillation Prediction Observations Research Task (SPORT): A Spacecraft Development for an International Mission," Proceedings of the 32nd Annual AIAA/USU Conference on Small Satellites, Logan, UT, 2018.
7. Forsberg, K. and Mooz, H. "The Relationship of System Engineering to the Project Cycle". INCOSE International Symposium, 1: 57-65. 1991 doi:10.1002/j.2334-5837.1991.tb01484.x
8. Bandecchi, M.; Melton, B.; Gardini, B.; Ongaro, F. The ESA/ESTEC Concurrent Design Facility. In: Proceedings if EuSEC 2000.
9. Sillitto, H., Martin, J., Griego, R., Mckinney, D., Arnold, E., Godfrey, P., Dori, D., Krob, D. and Jackson, S. (2018). Envisioning Systems Engineering as a Transdisciplinary Venture. INSIGHT. 21. 52-61. 10.1002/inst.12212.
10. Dori, D. Model-Based Systems Engineering with OPM and SysML. New York: Springer, 2016. ISBN 978-1-4939-3294-8
11. Voirin, J. "Model-Based System and Architecture Engineering with the Arcadia Method" Elsevier, 2018, ISBN 9781785481697