AerospaceEurope Conference2021
WARSAW, POLAND | 23 -26 NOVEMBER 2021
CEAS Council of European Aerospace Societies

LESSONS LEARNED FROM HANDS-ON NANOSAT ACTIVITIES IN PEGASUS UNIVERSITIES

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Abstract

Since about 30 years, several Universities belonging to the PEGASUS (Cranfield University, Politecnico di Milano, Politecnico di Torino, Sapienza Università di Roma, TU Berlin, TU Delft, Università di Bologna, University of Glasgow, Universidad Politecnica de Madrid, Università di Napoli "Federico II", University of Stuttgart, University of Zilina, to name a few) have been (or are still currently) involved in hands-on nano-/micro-satellite programmes. Whether these projects led to an actual spacecraft launch or not, it is undeniable that the practical design and assembly experience can enrich the curricula of the involved students in an unbeatable way. This paper provides an overview of the hands-on nanosat activities and projects run by PEGASUS universities putting them in the context of the ESA-led satellite educational projects. Then one representative case study, namely ESEO microsatellite mission operational phase, is discussed in more detail highlighting the main challenges which needed to be faced, the achievements, and the lessons learned.

Keywords: PEGASUS universities – nanosatellites – hands-on educational activities

1. PEGASUS and its role in ESA-led educational satellite programmes

PEGASUS partnership of European aerospace universities currently has 28 members in 11 different European countries. Among its well-established aerospace-related educational and research programmes, nano-/micro-satellite projects certainly assume a pivotal role.

Almost all hands-on nano-/micro-satellite programs in the early phases considered a full end-to-end mission design and implementation – S/C bus, payload(s), Mission Control, Ground Segment – with substantial component and subsystem developments (the build-versus-buy decision matrix was typically imbalanced toward the former). However, since the introduction of the CubeSat standard in 1999, and the broad availability of standardized nano- and micro-sat components and subsystems, three main trends emerged: (a) new H/W developments were minimized and the team efforts were devoted to clever designs, assembly and testing; (b) complete CubeSat bus solutions were selected and used by those teams focusing on new P/L developments; (c) 1U CubeSats gradually left room to 3U (and even 6U) CubeSats which allowed to host more challenging experiments and provided more electrical power thanks to the larger (and potentially deployable) solar panels.

The European Space Agency and the ESA Academy (formerly ESA's Education Office) participated actively in this process. Aimed at improving students' skills and competences for the space sector, boosting their motivation to be engaged in the space domain, and to offer a direct experience on a real space project, ESA Academy promoted different hands-on projects. In 2000, the Student Space Exploration and Technology Initiative (SSETI) was established, which main objective consisted in creating a network of students, educational institutions and organizations on the Internet, which together would own the capability and the means to design, build and launch a micro-satellite. Since the beginning of the SSETI initiative, students from around 20 different universities throughout all Europe engaged in the development of the very first SSETI microsatellite, named as the 'European Student Earth Orbiter (ESEO). After the launch of SSETI Express in 2005, ESEO became the second ESA student satellite, and it was meant to be the technical precursor of the SSETI European Student Moon Orbiter (ESMO). Several student teams were dedicated to the development of the different subsystems and payload complements, and the launch was at that time planned in 2008, with Soyuz or Ariane 5. The SSETI-ESEO team tried a few times to pass the Preliminary Design Review (PDR), without success despite the efforts**.**

The ESA Education Office then decided to continue offering the ESEO experience to university students, but decided to rely on the coordination of an industrial Prime Contractor and System Integrator for the satellite platform. After a short experience with Carlo Gavazzi Space (currently OHB Italia), because of financial issues the Education Office decided to change approach, readdressing the project towards a smaller baseline, in order to maintain a high educational impact, but with more affordable time, technical and cost-related boundaries. Following a competitive tender, a new System Prime was selected. ALMASpace, a spin-off company of the University of Bologna later absorbed by SITAEL, was awarded the contract to redefine the ESEO baseline, and to coordinate and supervise the ESEO students teams from the technical point of view. With SITAEL, under the coordination of ESA, the satellite reached its final configuration and mission profile. In its final configuration, ESEO had a clear educational objective: for the participating university students to acquire *hands-on experience of a real space project*, in order to prepare a well-qualified technical workforce for the European space sector. Following trend (b) illustrated above, students were offered the opportunity to develop the payload (scientific instruments or technology demonstration experiments), key satellite subsystems and the ground segment (ground stations and Mission Control) to the mission, while the satellite platform was under responsibility of the industrial contractor. Since its beginning, and throughout all its phases, the ESEO programme involved more than 600 students from ESA Member States, including students from PEGASUS members (i) University of Bologna (IT), (ii) TU Delft (NL) and (iii) Cranfield University (UK).

The ESEO engineering activities performed by the university teams have been complemented by a series of additional learning opportunities during the execution of the project. Lectures dedicated to the students participating in the ESEO project were organised by the University of Bologna, the ESEO university network coordinator. In particular, 3 editions of lecture courses and internships took place between September 2013 and September 2014. Each edition included a two weeks course (one week with lectures related to space disciplines, and the second week concentrating on ESEO related subjects) followed by a third one in the form of an internship at ALMASpace premises. University credits (ECTS) were recognised to all participants. Later, training Sessions at the ESA Academy's Training and Learning Centre at ESEC, Belgium have been organised, aiming at offering a more complete preparation in satellite telecommunications and operations, especially oriented to those teams who were to be involved in the spacecraft operations. At the conclusion of the spacecraft testing campaign, an additional workshop for the ESEO university teams was organised at ESTEC by the ESA Education Office in late 2018. Space engineers and satellite test experts from space industry and ESA shared with the students all the processes and the technical issues that had to be solved during the satellite test campaign, in order to give students the opportunity to reinforce their know-how and understanding of satellite engineering as a whole.

Two in-flight experience workshops were also held, one in Redu in August 2019, and one held remotely in October 2021, to deep-dive into lessons learned from the development and operations of ESEO, its anomalies and overall mission results.

2. Overview of the hands-on nanosat/space systems activities within PEGASUS

2.1 Alma Mater Studiorum – Università di Bologna (UNIBO)

Since 2003, the Alma Mater Microsatellite and Space Microsystems (u3S) Lab at the University of Bologna carries out research activities on space technology. The focus is on micro-nano satellite platforms, that better fit the university budget constraints and the educational outreach, since they represent a cost-effective test-bench where students can learn by doing, having the opportunity to participate in the entire space project lifecycle, including on-orbit operations.

The Lab activities started with the ALMASat-1 project [1], a microsatellite launched in 2012: more than 60 BSc, MSc and PhD students took part to the entire satellite development.

Building on the success of the ALMASat-1 experience, the laboratory had a role in supporting the European Student Earth Orbiter (ESEO) [1]. University of Bologna (UniBo) contribution to ESEO programme covered different areas, namely being i) responsible for the educational activities for the EU students belonging to the ESEO University Network [1]; ii) in charge of the development of the GPS-based navigation subsystem [3], and iii) responsible for the development of the ground segment [4] and the mission control centre.

Remarkably, being in charge of the mission control centre allowed students to gather experience in real-time operations of a satellite mission, which proved to be an invaluable source of lessons learned (see Section 3).

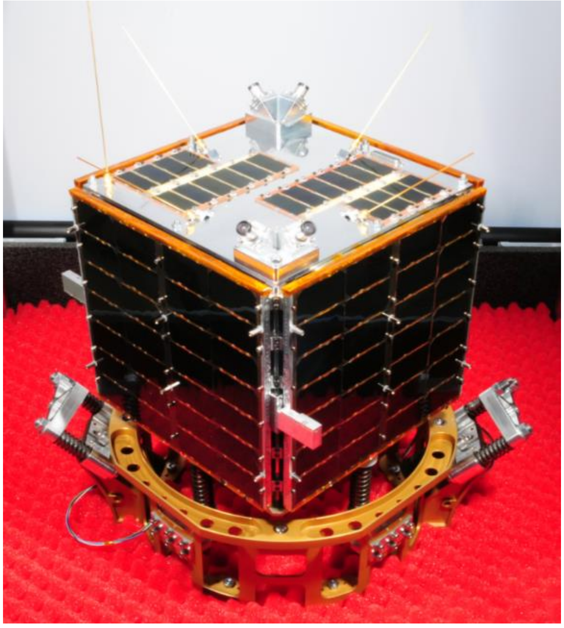

Figure 1 – ALMASat-1 on the launcher adaptor/separation system.

Following the industrial re-organization of its former spin-off AlmaSpace, the Microsatellites and Space Microsystems Laboratory is now focusing on the following target areas, closely related to, and further developing, the activities within ESEO: - autonomous navigation for satellites, space traffic management, experimental ground testing of attitude determination and control equipment.

Figure 2 – ESEO GNSS Navigation subsystem.

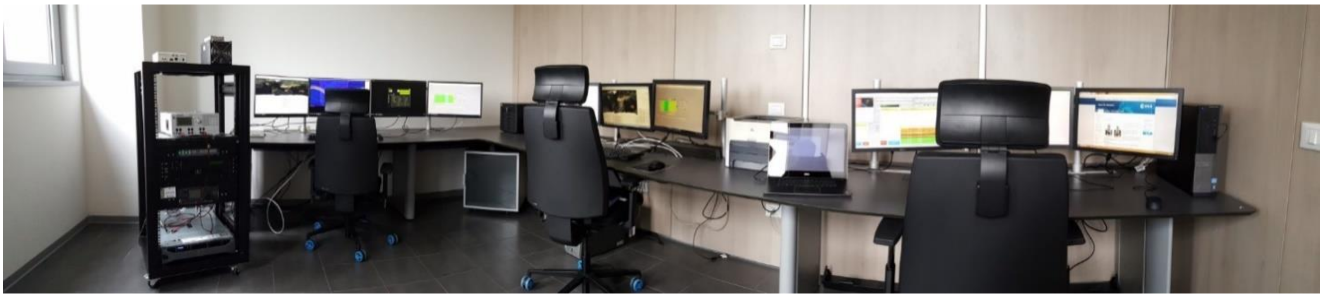

Figure 3 – ESEO Mission Control Centre at University of Bologna – Forlì Campus.

2.2 Universidad Politécnica de Madrid (UPM)

Since the 1990s, the UPM has promoted the UPMSat's nanosatellite program as a fundamentally educational project, with strong scientific and technological development components. The aim of this program is to create the ability to design, develop, build, test, integrate, and operate a spacecraft within the university environment. The first satellite of this program, the UPM-Sat 1, was a science and technology demonstration satellite launched in 1995, becoming the first Spanish university satellite. In 2014 the UPM implemented the Master of Space Systems (MUSE) [5], a two years master focused on the design of satellites and very oriented towards the Project Base Learning methodology [6]. To provide the additional element of practical work that the students needed, the UPM decided to resume the UPMSat program with a new satellite, the UPMSat-2 [7]. This 0.5x0.5x0.6 m and 50 kg nanosatellite was successfully put into orbit on September 3, 2020; and as of November 2021, it is still in operation. The UPMSat-2 was the result of the close collaboration of MUSE students and teachers during all its development stages: design, construction, testing and operation. The UPMSat-2, as its predecessor, was aimed at the technological demonstration, including several sensors and instruments that had not been tested in orbit (magnetometers, reaction wheels, thermal switch ...) as well as several experiments of the IDR/UPM [8],[9]. After the success of the mission, the UPM plans to continue with the UPMSat program, with future satellites that serve as support to the MUSE master. In addition to the UPMSat program, the UPM actively collaborates with other universities in nanosatellites projects. Among these collaboration networks are BRAIA an alliance of 51 aerospace universities, research institutes and academic organizations in the aerospace field; and the NanoStar program [10] a network of excellence among universities, regional industry, and the scientific ecosystem oriented to create a leading platform in Europe on nanosatellites.

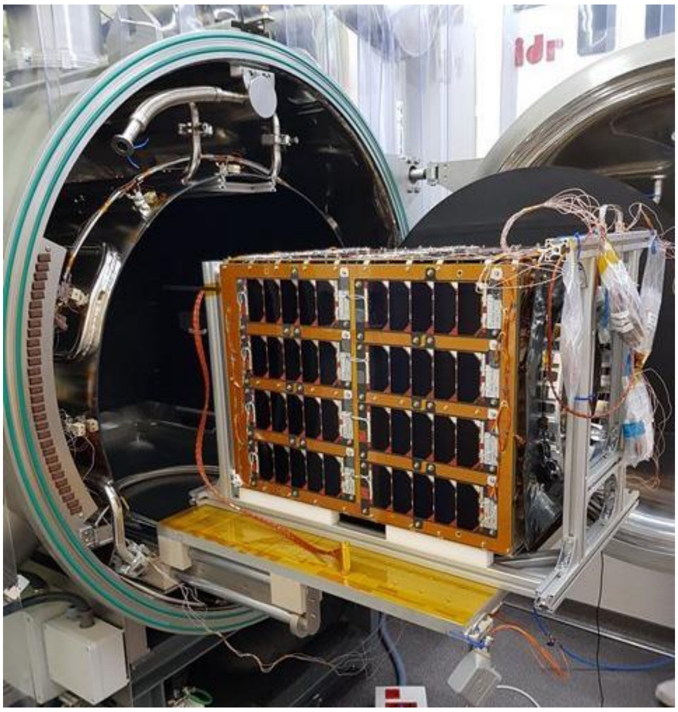

Figure 4 – The UPMSat-2 during the thermal tests.

2.3 University of Zilina (UNIZA)

After five years of development under the research project, the first Slovak satellite skCUBE had been launched into space in 2017. Designed and constructed completely in Slovakia by the Slovak Organisation for Space Activities, three excellent Slovak universities – University of Zilina, Slovak University of Technology in Bratislava, Technical university of Kosice and other partners from industry. Top scientists at the University of Zilina had the opportunity to collaborate on this project in cooperation with students, where they jointly developed new technologies implemented in the satellite. Weighing about 1 kg, skCUBE is a 10-centimeter cube that carry an onboard computer, a communications system, and a small camera to conduct experiments when orbiting Earth. SkCUBE was also backed by the government and could serve as an example of cooperation between universities, students, companies, and other supporters. New project is currently being prepared to develop another satellite to perform new tasks in space.

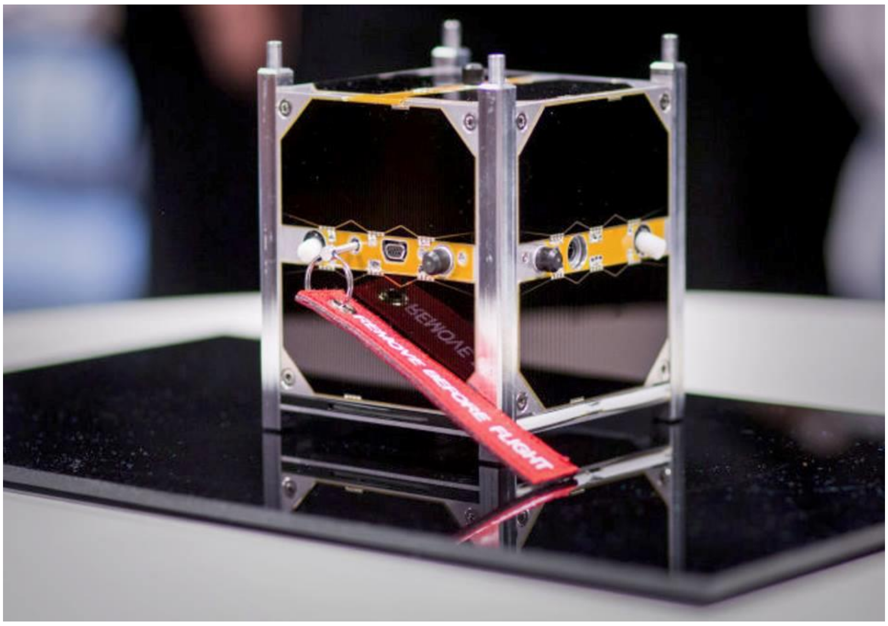

Figure 5 – SkCube assembled – Source [11]

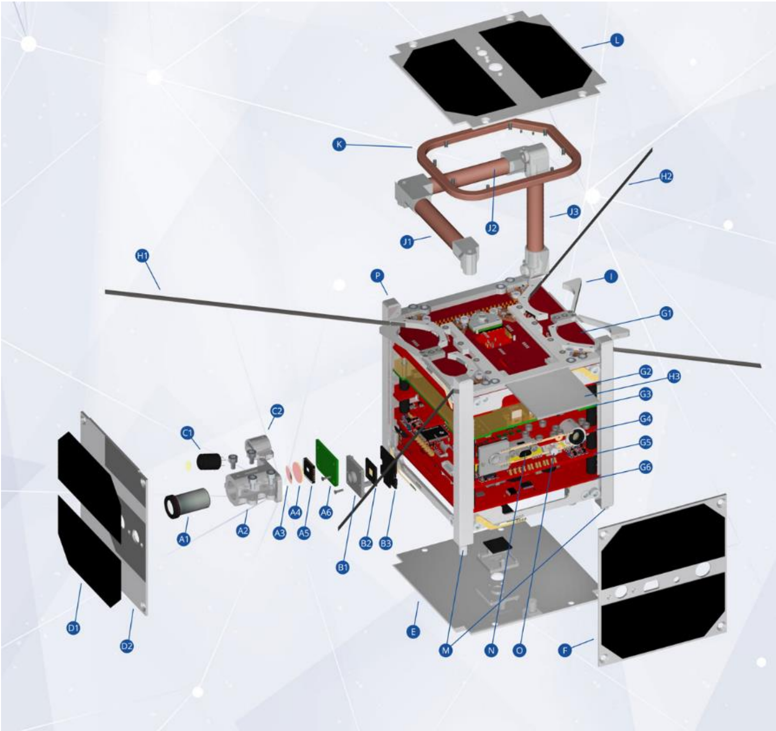

Figure 6 – SkCube, exploded view - Source [12]

2.4 University of Glasgow (UofG)

Nano-satellite development activities at the University of Glasgow are led by a student society, GU Orbit (Figure 7 left), led by current president Jorge Dario Arredondo De Vega, under the guidance of academic staff within the Space and Exploration Technology (SET) group, James Watt School of Engineering.

The society aims to bring students into the world of space systems, focusing on developing micro-satellites with a specific mission in mind, with the ultimate goal to launch them into orbit. The society provides a gateway for students who are passionate about space and gives them an opportunity to learn about small satellite technology while getting hands-on experience in developing a CubeSat, aiming to become a significant space research contributor in Scotland and to be the first Scottish student-led group to design, manufacture and launch a CubeSat. The society currently comprises of 60 members of many different disciplines and degrees, including BEng, BSc, MEng, and PhD.

The current main project of GU Orbit is Astraeus-1 (Figure 7 right). Astraeus-01 is designed as a 4-year, low Earth orbit, 3U CubeSat mission that will serve as a space demonstrator for two key technologies:

1) A three-dimensional self-stable drag-sail to de-orbit the satellite quickly and mitigate the build-up of space debris, supporting the sustainable use of the near-Earth region.
2) An on-board graphics processing unit (GPU) with custom-made software will demonstrate image compression and processing onboard the CubeSat. Other payloads will be included such as an in-house made on-board computer (OBC), electrical power subsystem (EPS) (as seen in Figure 8) and magnetorquers for the ADCS.

Astraeus-1 has recently completed the first preliminary design review (PDR), and it is currently undergoing its critical design review (CDR). Spacecraft components are now being manufactured and tested by the teams, critically the GPU is being tested for heat conduction under vacuum conditions. Finally, a Ground Station is being built.

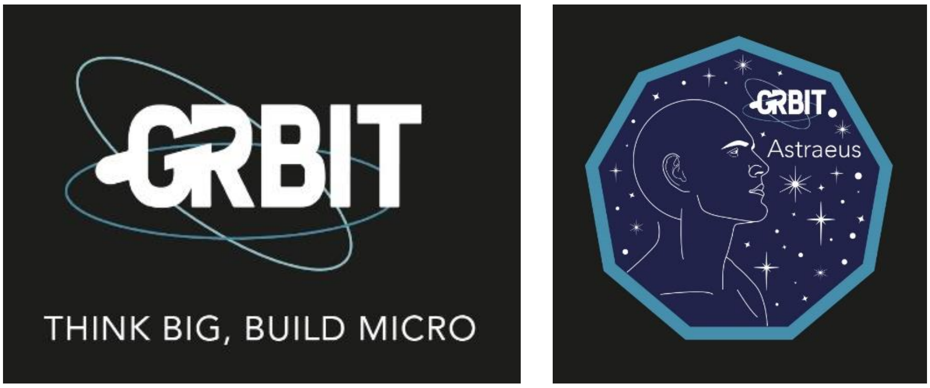

Figure 7 – GU Orbit logo and Astraeus mission patch

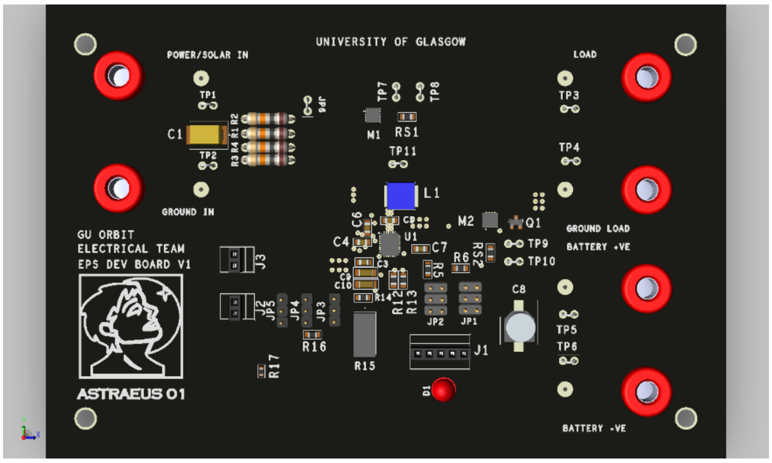

Figure 8 – EPS development board

3. Lessons learned from operating an educational microsatellite mission: the ESEO case study

In the framework of the ESEO project, University of Bologna was in charge for the design and development of the Mission Control Centre (MCC), the implementation of the primary ground station for telemetry and telecommand operations, and of the secondary one for the downlink of payloads data. The primary TMTC ground station operates in the Ultra-High Frequency (UHF) band for uplink and downlink (430-440 MHz). The Secondary Science Data ground station operates in S-band, and uses a parabolic dish antenna with a septum dish feed.

A dedicated control room was set up and equipped to support the mission monitoring and control related activities. It hosts three workstations and the Radio Frequency equipment such as switches, High Power Amplifiers and radio interfaces. A first workstation is dedicated to the control of the RF front-end and the Antenna tracking, one is a spare for future missions, and the third workstation was entirely dedicated to the ESEO mission. It hosted the mission control software, from the database storage to the Spacecraft Monitoring and Control (M&C) system for commanding the spacecraft and visualizing telemetry.

The preparation and test of the flight procedures were the core activity of the University of Bologna during the preparation-to-launch phase. To this end, a list of draft operations in the form of raw commands sequences were provided by the industrial prime contractor, SITAEL. These sequences have then been expanded and tailored to the Ground Segment setup, with focus on the M&C Software interface outlining the flight operations procedures.

ESEO was launched on December 3rd, 2018. Shortly after the launch, ESEO's downlink seemed to work properly, but it appeared that the commands coming from the GS were not received by the spacecraft. Several Materials Review Boards were held along with ESA's experts and SITAEL's engineers to investigate and solve the issue. Time efficiency was crucial in this phase and actions were taken on different levels: from the inspection of the RF chain and the M&C SW, to the check of the antenna pointing. In parallel, other ground stations were contacted, some of them having significant higher EIRP than the primary TMTC one, for establishing a first contact with ESEO. Eventually, thanks to the support of the radio amateur community and of ES5PC ground station in Tartu, a successful contact with ESEO was established and LEOP activities could be resumed in February 2019. Having a solid network of ground stations is fundamental in a space mission, and coordination among partners is a key factor during LEOP: certainly, this is a lesson learnt from ESEO.

Since then, new challenges came, which needed to be faced for the mission to advance further, including the non-nominal spacecraft attitude, a single event upset requiring an On-Board Data Handling (OBDH) system reset, and the periodic loss of modulation of the received packets on ground due to timing issues with the high-power amplifier. Nonetheless, extensive investigations on the anomalous behaviours were performed and, despite not all of them being solved, the commissioning phase of the educational payloads began: the AMSAT-UK transmitter, the S-band transmitter from Wroclaw University and Tartu Observatory CAM were successfully operated starting from March 2019, before the mission was forced to end on the 20th of April 2020 due to a major bus voltage drop. Prior to that, the CAM payload was activated twice and 6 pictures were decoded in total. A great reward for the huge, long-lasting efforts, thanks to an effective team-work among the several actors involved.

4. Conclusions

During the past three decades, micro- and nano-satellites programmes have been a fruitful source of hands-on projects in aerospace education, as it is proved by several of such activities run by PEGASUS universities, often in the context of ESA-led satellite educational projects.

On one hand, the enrichment brought by the practical design and assembly experience to the curricula of the involved students is undeniable. On the other, the challenges and unpredicted issues that inevitably students must cope with during projects of such complexity represent a chance of educational and professional growth.

From the review of some of these projects some useful lessons can be drawn:

- a self-organized (but non-coordinated) set of university student teams cannot meet the objectives of a real space project, because schedule control and team interaction are of outmost importance;
- a time-consuming nano-/micro-sat student project needs to be recognized as part of the students' study plan in terms of university credits, otherwise the commitment and the engagement (once the initial enthusiasm is over) will never be high enough to allow reaching the challenging goals of a real space project;
- working closely with experts from space agencies and industry is an invaluable asset for the university teams, especially in those project phases where unexpected problems requiring high responsiveness need to be faced;
- management of time/resources and coordination among partners are pivotal for the success of nano-/micro-sat student projects.

5. Acknowledgments

The authors wish to acknowledge the support from ESA Academy received by most of the projects described in this manuscript.

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7. Copyright Statement

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