Lessons learned during the development of LEDSAT from the students of the S5Lab

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Abstract

The LEDSAT 1U Cubesat, a satellite roughly 10x10x11cm, was developed between late 2016 and 2021 by students of Sapienza University of Rome. The project was conceived with the help of the University of Michigan and started being developed by space engineering master students of Sapienza in a class context. The team of the S5Lab (Sapienza Space System and Space Surveillance Laboratory) continued the project and applied for the Fly Your Satellite! Programme of ESA Education, which has followed the development of the CubeSat, providing important expert support and periodic reviews. The approach brought to the students an invaluable educational experience as they participated actively in the development of a spacecraft with the typical milestones of satellite projects. The mission objectives of LEDSAT include the use of onboard LEDs for improved orbit determination, experimental attitude determination and backup light communication. Each of the six sides of the CubeSat houses an LED board of a different color (red, green, and blue) with opposite sides with paired color. The LEDs can flash a pattern predefined by radio telecommand and the light is observed using ground telescopes. The design of the spacecraft started in late 2016 and was presented at the selection workshop of the Fly Your Satellite! Programme in May 2017. Final assembly took place in mid-2020 after which the team performed functional and environmental testing between October and December 2020, with the objective of ensuring the survivability of the spacecraft in the space environment and characterization of its behavior. After successful testing, the spacecraft was integrated inside the deployer in July 2021 in Brno, Czech Republic and was launched from Kourou, French Guiana on August 17th, 2021, aboard the Vega VV19 launcher. The spacecraft is now in orbit and operating nominally, with the LED flashes having been observed several times. The development of the spacecraft was not without difficulty, with preventable issues arising through testing that imposed design changes and further analysis - the paper will walk through the project since its conception, throughout the development, the functional and environmental testing of the payload and at system level, emphasizing the lessons learned by the students.

Keywords

CubeSat, nanosatellite, lessons learned, education

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Acronyms/Abbreviations

All used acronyms and abbreviations should be listed in alphabetical order, as follows:

FYS	*Fly Your Satellite*
ESA	*European Space Agency*
CDR	*Critical Design Review*
AIV	*Assembly, Integration and Testing*
TLE	*Two-Line Element*
FFT	*Full-Functional Test*
MT	*Mission Test*
CSF	*Cubesat Support Facility*
VIB	*Vibration*
TVAC	*Thermal-Vacuum*
TID	*Total Irradiated Dose*
LSA	*Aerospace System Laboratory*

1. Introduction

LEDSAT is a 1U CubeSat developed by Sapienza University of Rome, in collaboration with the University of Michigan [1], [2]. The mission aims at verifying the functionalities provided by on-board LEDs for the orbital determination and experimental attitude determination from ground, using telescopes to observe the satellite [3]–[7]. The idea was developed in 2016, in the context of a spacecraft design class in a Master's course in engineering and was presented to be part of the Fly Your Satellite! Programme (FYS) of ESA Education in 2017. The programme followed the development of the spacecraft through CDR (Critical Design Review), AIV (Assembly, Integration and Verification) and launch. A picture of the satellite can be seen in Figure 1.

The satellite was successfully deployed in orbit on August 18th, 2021, and observation of the LEDs began as soon as possible. Within a week, the team had confirmed the object number assigned by NORAD for the TLE (Two Line Elements).

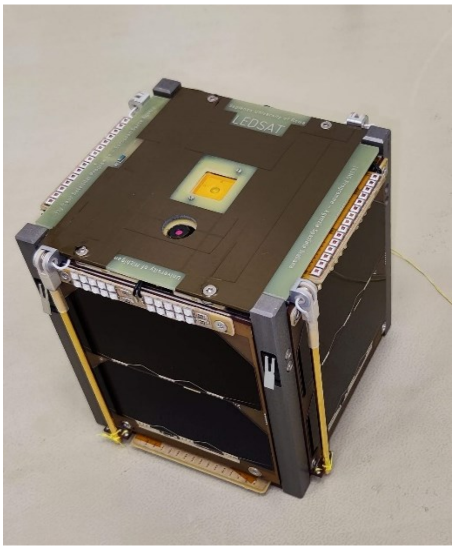

Figure 1: LEDSAT before integration into the deployer.

2. Mission timeline

The concept was developed in 2016 by the University of Michigan and was followed on by a spacecraft design class in Sapienza University of Rome in the second semester of 2016 (Figure 2). There, students turned the mission concept into a 1U CubeSat, designing and sizing the components of the nanosatellite in order to sustain the payload. What was developed within the class was used to draft the proposal for FYS, to which the team applied in 2017.

Figure 2: Students that developed the mission concept.

The Selection Workshop for FYS took place in May 2017 in ESTEC, Noordwijk, where five students presented the mission to an ESA experts panel for the admission into the programme (Figure 3).

Figure 3: Students presenting LEDSAT at the FYS Selection Workshop.

The CDR took place between fall of 2017 and spring of 2018, with co-location meetings that took place in ESTEC, Noordwijk in December of 2017. During the co-location meetings the team defended the design to several experts for each major subsystem and went through all the design changes (Figure 4).

Figure 4: Students at the co-location meetings at ESTEC.

Before assembly the team underwent a testing campaign related to the LED payload with the help of the FYS Team. In particular, the LEDs were subject to radiation testing (December of 2017) at the Co60 Facility in ESTEC. At the Co60 facility the team performed TID testing (Total Irradiation Dose) and learned how space hardware is tested against a gamma ray source.

The payload boards also underwent vibration and thermal-vacuum testing at the CubeSat Support Facility (CSF) in ESEC Galaxia in November of 2019 (see Figure 5), where the students familiarized themselves with the test equipment, the procedure writing and the operations [8].

Figure 5: Students performing the TVAC testing on the payload at the CSF.

Assembly of the spacecraft took place in the beginning of 2020, after which the satellite underwent functional testing in July 2020, with a Full Functional Test (FFT). During the FFT, an anomaly in the GPS receiver was found that made it unable to get a position fix. The root causes of the problem were found and fixed, after which the testing resumed from the FFT and through the Mission Test (MT) [9].

With all the functionalities tested, the team performed the environmental testing at the end of 2020, with both Vibration Testing (VIB) and Thermal-Vacuum Testing (TVAC) performed at the facilities of Sapienza University of Rome, at the Aerospace System Laboratory (LSA). The tests were originally planned to be performed at the CSF, but due to travel restrictions causes by COVID-19 they were performed at the university. A picture of LEDSAT in the TVAC chamber in Sapienza can be seen in Figure 6.

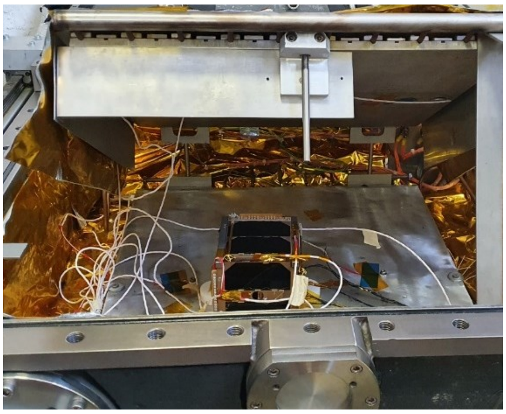

Figure 6: LEDSAT inside the TVAC chamber.

Upon changes on the environmental requirements from the launch authority, it was found necessary to perform additional tests on the CubeSat. To this end, the team travelled to the Astrofein facilities in Berlin to perform a shock test on the payload EM (Engineering Model) in May 2021 and to the CubeSat Support Facility (CSF) in ESEC Galaxia in June 2021 to perform new vibration and thermal-vacuum testing on the PFM (Proto-Flight Model), see Figure 7.

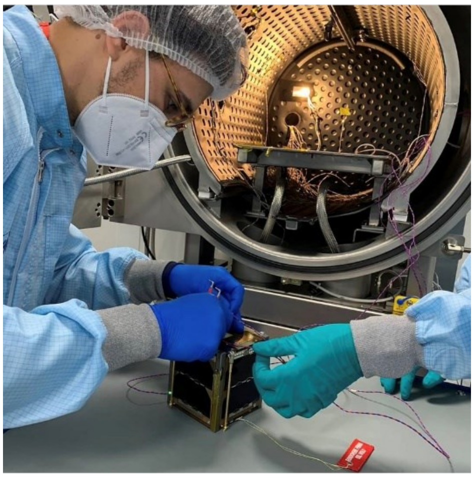

Figure 7: LEDSAT being prepared for TVAC testing at CSF.

The CubeSat was finally integrated into the flight deployer in Brno, Czech Republic in July 2021. The team assisted in the integration of the deployer on the PLA (Payload-Launcher Adapter) at CSG (Guiana Space Center) in French Guiana at the end of July 2021 (Figure 8).

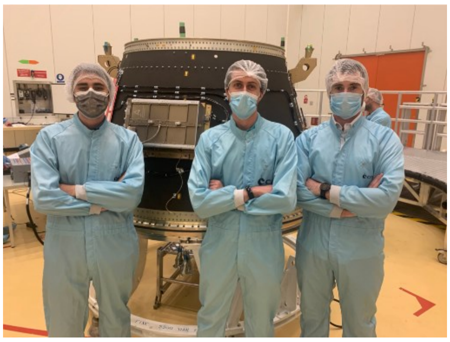

Figure 8: Students and FYS Team member at CSG, next to the PLA.

Deployment of the satellite into orbit took place on August 17th, 2021, brought to orbit by the Vega VV19 launcher. First contact with the spacecraft occurred soon after deployment, from the Ground Station (GS) in Rome.

The first observations of LEDSAT took place one week after launch and were successful, confirming which object was LEDSAT among the five released by the launcher. Operations continue with the observations of different patterns, optimizing the observation times and testing the experimental attitude determination. An example of LEDSAT flashes can be seen in Figure 9.

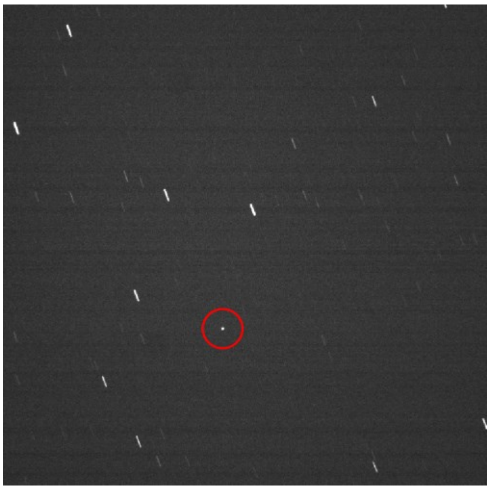

Figure 9: LEDSAT flashing during an observation session.

3. Specific Lessons Learned

3.1. Difficulty in increasing team size

It was difficult to allow new students to join the team and to let them participate in AIV activities. While in the order of 40 students have participated in some way in the

LEDSAT mission, only 6-7 were actually involved in the development of the hardware. The main difficulty was due to the steep learning curve necessary to work with the hardware safely, and the difficult problems that required experience in the mission to solve. It was difficult to divide the work into smaller tasks that new students could perform. A solution could be to give small preparatory courses to train the students and introduce them to the CubeSats environment.

3.2. Test procedures

One issue that was noted soon was the difficulty in writing good test procedures. Producing an effective procedure was an important lesson during the development of the satellite, but since most things were done for the first time it was difficult for the procedure writers to imagine the steps necessary and for the operators to perform them. In the end, the result was over-detailed procedures that could not always be followed fully during the operations, or that slowed the operations altogether. In addition, since most of the time the procedure was written by the same person performing it, most of the details were unnecessary. A solution to this problem could be to structure the step-by-step procedures to be more like checklists.

One of the main benefits of a step-by-step procedure is to have good traceability of what was performed on the spacecraft, but this can easily be replaced by pictures – in fact, the team found that looking at pictures taken during the operations was a far better and faster way to recall and retrace the details of what was performed. With this mindset, the operators should take pictures at every key point of an operation, with ideally an operator assigned specifically to this task.

3.3. Keeping good documentation

An important lessons learned during the project was the need to keep good documentation updated. The documentation helped a lot to recall old details of the project easily, keeping track of all the changes to the design and all tests. One will never know when a particular information will be needed and must plan for the future. In addition, the documentation helps in allowing new personnel to join the team and to share the details across the team.

3.4. Help from the radio-amateurs

Since the satellite uses radio-amateur frequencies in UHF, it is also received by radio-amateurs. The team has found that the radio-amateur community is happy to help in receiving the satellite and help in the first phases of the mission, where receiving the first signals is crucial. To this end, the community has developed the project SatNoGS, whose objective is to provide an open source network of satellite ground stations. The team provided the information necessary to demodulate and interpret the data of the telemetry and the stations of SatNoGS regularly schedule and receive the satellite signal, also storing the received telemetry in their databases. This can be very useful when there are problems at the ground station, and highlights the importance of transmitting a periodic beacon with the vital telemetry inside.

3.5. Focus on the flight operations

The team found it was very important to focus on the real-life operations to be performed while the satellite is in orbit, and to this end the Mission Test was crucial. Working with the satellite in ground, with the different debug connection, easy access and other aids is very different then operating the spacecraft in orbit, where visibility of the on-board software and short access times limit what the operators can do. At the same time, the space environment is different in many aspects, like temperature and battery charging profiles that could affect the operations.

It is key then to test the different scenarios however possible, recreating the access times and communication speeds to see if the operators have good control of the spacecraft or if some function needs to be changed.

4. Conclusions

The LEDSAT mission developed by students of the University of Rome in collaboration with the University of Michigan between 2016 and 2021. The satellite is currently in orbit and performing nominally, with the observations of the on-board LEDs continuing. The project involved about 40 students, between Bachelor, Masters and PhD students and was part of the Fly Your Satellite! Programme, which provided extended help in the project, both technical and educational. Several lessons were learned in the project, which are used in current and will be used in future projects of the laboratory.

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