Update on the status of the Educational Irish Research Satellite (EIRSAT-1)

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Abstract

The Educational Irish Research Satellite, EIRSAT-1, is a 2U CubeSat being implemented by a student-led team at University College Dublin, as part of the 2nd round of the European Space Agency's Fly Your Satellite! programme. In development since 2017, the mission has several scientific, technological and outreach goals. It will fly an in-house developed antenna deployment module, along with three custom payloads, which are integrated with commercial off-the-shelf subsystems.

In preparation for the flight model, a full-system engineering qualification model of the spacecraft has undergone an extensive period of test campaigns, including full functional tests, a mission test, and environmental testing at the European Space Agency's CubeSat Support Facility in Redu, Belgium.

Beyond the technical, educational, and capacity-building goals of the mission, EIRSAT-1 aims to inspire wider study of STEM subjects, while highlighting the importance of multidisciplinary teams and creating greater awareness of space in everyday life. A wide range of outreach efforts ensure these aims are achieved.

This paper provides a status update on key aspects of the EIRSAT-1 project and the next steps towards launch.

Keywords

EIRSAT-1, CubeSat, Fly Your Satellite!

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1. Introduction to EIRSAT-1

EIRSAT-1 is a 2U CubeSat under development by a student-led team at University College Dublin (UCD) [1]. The project, which aims to launch Ireland's first satellite, is supported by the 2nd edition of the European Space Agency (ESA) Fly Your Satellite! (FYS!) programme.

EIRSAT-1's fundamental objectives are educational [1]. However, additional scientific and technology demonstration aims are also being achieved with three novel payloads, known as GMOD [2, 3], EMOD [4, 5] and WBC [6]. In addition to custom-built payload hardware, EIRSAT-1, shown in Figure 1, will fly an in-house developed antenna deployment module (ADM) [7] and commercial-off-the-shelf (COTS) components. To reduce risk and build expertise on spacecraft development within the team, two separate models of EIRSAT-1 are being built **–** an engineering qualification model (EQM) and a near-identical flight model (FM).

This paper provides an update on the status of the EIRSAT-1 project. Progress made with the EQM will be the focus of this discussion. Given the project's educational objectives, the team's outreach efforts during this time will also be discussed. Finally, the remaining steps towards a 'ticket to launch' will be reviewed. In addition to providing a project update, this work also aims to offer insight into the lifecycle of a CubeSat project participating in ESA's FYS! programme, the 4th edition of which was announced in October 2021. While not explicitly discussed in this work, it is worth noting that the project timeline presented has been impacted by the COVID-19 pandemic as, e.g., the possibility of travel and use of test facilities were highly restricted throughout 2020/21.

2. Building the EQM

Following selection to the FYS! programme in May 2017, the EIRSAT-1 mission design was subject to a critical design review (CDR). As part of this review, detailed documentation (spanning hundreds of pages across several documents) was produced and then reviewed by the FYS! team as well as ESA experts. After several review cycles, the successful close-out of this CDR was announced in September 2018, allowing the EIRSAT-1 team to proceed with more hands-on development of the EQM.

2.1. EIRFLAT-1

The EQM parts of EIRSAT-1 were initially assembled on a FlatSat [8]. A 'FlatSat' refers to a tabletop configuration in which the satellite is assembled on a large motherboard or series of motherboards laid out horizontally. Although configured differently, all satellite parts connect in an electrically flight-representative manner. The main advantage of a FlatSat is that components are easily accessible throughout testing.

A fully populated EQM FlatSat of EIRSAT-1 was assembled over the course of several months [8], as COTS components were received and acceptance tested, and as custom-built payloads were developed, tested and space qualified [9, 10, 11]. This FlatSat was then subject to a functional test campaign, for which formal test documentation was specifically developed. Although FlatSat-level testing to this extent is not a requirement of FYS! 2, this testing was carried out to reduce risk by ensuring key functions of the spacecraft's subsystems work reliably as a complete system prior to final integration. This testing was found to be an invaluable learning experience for the team, with largely successful results [12].

2.2. EIRSAT-1

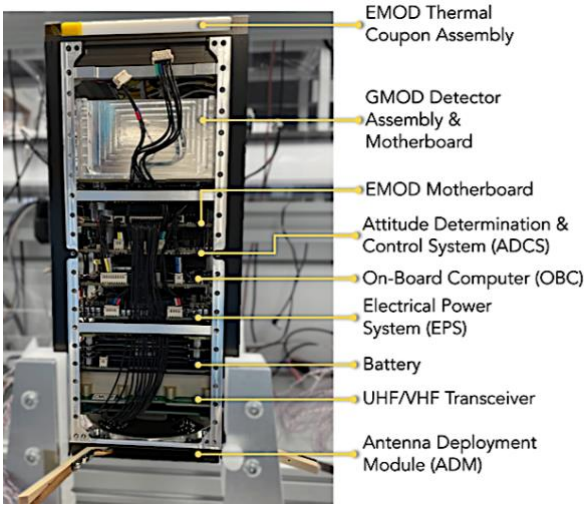

Figure 1. Stacked configuration of the EQM, showing EIRSAT-1's constituent components.

Following a successful FlatSat test campaign, the EQM FlatSat was disassembled.

On 23rd-25th November 2020, EIRSAT-1's EQM components were then integrated in a stacked configuration. A time-lapse demonstrating this integration process can be found here: https://www.esa.int/ESA_Multimedia/Videos/2019/04/EIRSAT-1_team_integrating_their_CubeSat

3. Testing the EQM

Once built, the EQM underwent a series of rigorous tests to verify that the spacecraft can satisfy the mission's requirements, which were defined during the CDR, and survive the extremes of spaceflight while doing so.

3.1. Ambient Testing

3.1.1. Functional Testing

Similar, but more extensive, functional tests to those performed on the FlatSat were repeated on the EQM following integration, starting in December 2020 [12]. Unlike the FlatSat tests, full system-level functional testing is required by all teams within FYS! 2.

This testing continued until July 2021, longer than nominally anticipated, due to four test anomalies (i.e., unexpected events that often lead to a test failure). Two of the anomalies, related to the ADM, were classified as major due to the associated risk to antenna deployment on-orbit. A redesign of the ADM was ultimately required. Following this redesign of the ADM, and its installation into the EQM stack, the relevant functional tests were then repeated and passed [12].

While these test anomalies impacted the project schedule, the comprehensive functional testing performed was successful in identifying and mitigating critical risks to mission success that were not previously known.

3.1.2. Mission Testing

EIRSAT-1's EQM mission test began on 3rd August 2021 [13]. A mission test is a long duration, flight-representative test in which realistic aspects of on-orbit operations are simulated in the expected in-flight sequence, starting from launch (Figure 2). This testing is also required within FYS! 2, and provides further confidence in the ability of the system to perform its intended mission on-orbit.

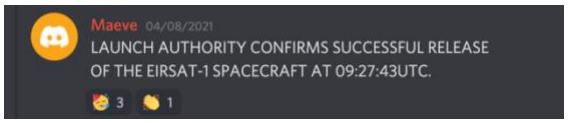

Figure 2. 'Launch' notification during EIRSAT-1's EQM mission testing.

The EQM mission test continued for 27 days continuously, until the 29th August. During this time, EIRSAT-1 team members took on the role of 'spacecraft operator', acting within the constraints of real on-orbit operations (e.g., limited 2-way communication time) to control the mission. In contrast to other tests, where activities are often suspended due to an anomaly, in this test, the operators were required to work through anomalies as part of the mission test simulation. This approach tests the mission's ability to manage faults and recover nominal operations.

EIRSAT-1's EQM mission test was largely a success in terms of achieving the predefined test objectives. Additionally, however, one of the most significant outcomes of the mission test relates to the operations experience gained through the simulation [13].

3.2. Environmental Testing

While all ambient testing was performed in one-of-two ISO class 8 cleanrooms located at UCD, adequate facilities for environmental testing, that is required as part of FYS! 2, were not similarly available. Therefore, on 13th September 2021, members of the EIRSAT-1 team travelled with the EQM to ESA's CubeSat Support Facility (CSF) in Belgium for vibration and thermal-vacuum (TVAC) testing [14].

3.2.1. Vibration Testing

Prior to testing, the EQM was integrated into a flight representative model of a 3U CubeSat deployer (Figure 3), along with a mass model of a 1U CubeSat.

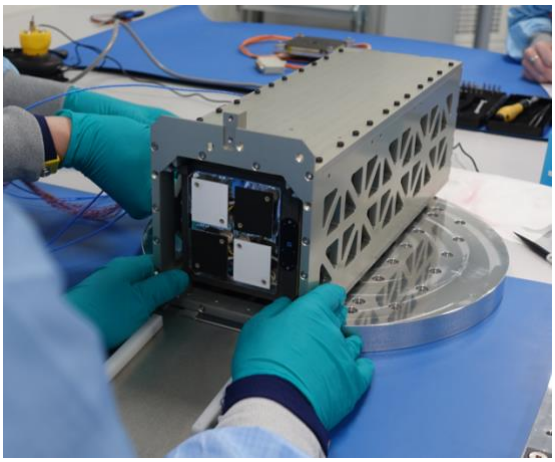

Figure 3. Integration of the EQM into a representative model of a CubeSat deployer.

The deployer was then mounted on an electrodynamic shaker table (Figure 4).

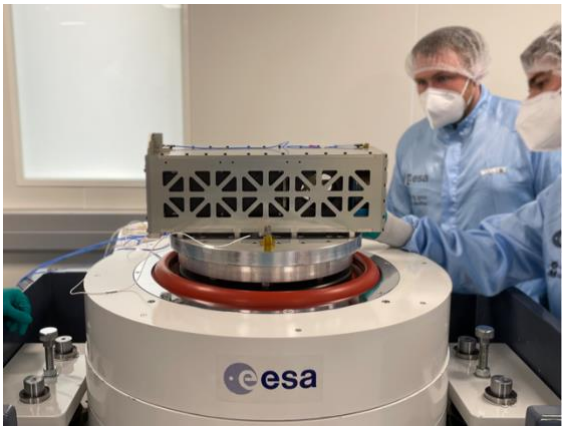

Figure 4. CubeSat deployer, containing the EQM, mounted on the shaker table.

Starting on 16th September, vibration tests were carried out, where each axis of the spacecraft

was tested separately. As part of these tests, each axis experienced a random vibration level of 14g (RMS), exceeding those expected during launch, for a period of ~2 minutes. This testing, which involved some data analyses as well as changes to the test set-up between axes, continued until 20th September, following which the EQM was removed from the test set-up and a health check was performed.
The health check (essentially a reduced functional test that had also been completed pre-test) proved that all critical subsystems (i.e., the EPS, battery, OBC and radio) had survived the launch-like vibrations. Unfortunately, however, it also revealed anomalous behaviour from the GMOD payload. On-site investigations suggested that some hardware damage to the payload was likely. This was later confirmed by analyses performed at UCD (see Section 4).

3.2.2. TVAC Testing

Although hardware damage to GMOD was suspected following vibration, the payload was still to some degree operational (e.g., it was capable of I2C communications with the OBC) and so, the decision was made to continue environmental testing. Therefore, on 27th September, the EQM was integrated into the CSF's TVAC chamber (Figure 5). The EQM was suspended in the chamber to ensure thermal isolation. Umbilical cables and thermocouples allowed communication with and monitoring of the EQM while in this test set-up.

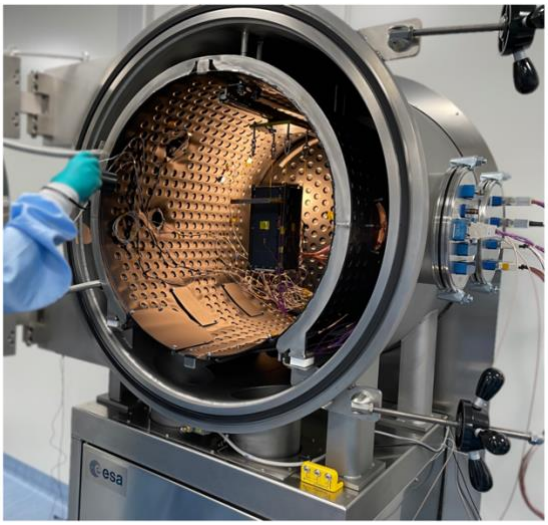

Figure 5. EQM integrated in the TVAC chamber.

During TVAC testing, the spacecraft was subjected to a vacuum of ~10^{-6} mbar, and temperatures ranging from −26°C to +56°C, while powered off, and −26 °C and +36.5 °C, while on [15]. When powered on, health checks were performed to ensure all subsystems functioned nominally under TVAC conditions.

Excluding GMOD (for which any health checks were modified to better assess the scope of the damage experienced during vibration testing), the EQM largely performed as expected throughout TVAC testing, providing confidence that the EIRSAT-1 spacecraft can survive the space environment. Minor anomalies that were encountered were either related to the test set-up or functions of the flight software which were impacted by the temperature conditions [15]. Crucially, the latter would likely not have been detected prior to launch without TVAC testing.

The EQM test campaign concluded following TVAC testing on 15th October 2021 [14].

4. Road to Flight

Since concluding EIRSAT-1's EQM test campaign, the team's key priority has been non-conformance reports (NCRs). NCRs document details on anomalies experienced throughout the campaign, suggest a root cause and, if required, propose mitigating solutions going forward. NCRs are then reviewed by FYS!, with input from ESA experts, and eventually closed when the anomaly is well understood and/or the mitigating solutions are satisfactory.

The EIRSAT-1 team is currently in the process of closing several NCRs generated most recently during environmental tests of the EQM, the most major of which requires a redesign of GMOD following investigations which proved a capacitor's solder joint was damaged during vibration testing. Once closed (or on track to close), the FM build will commence (Figure 6).

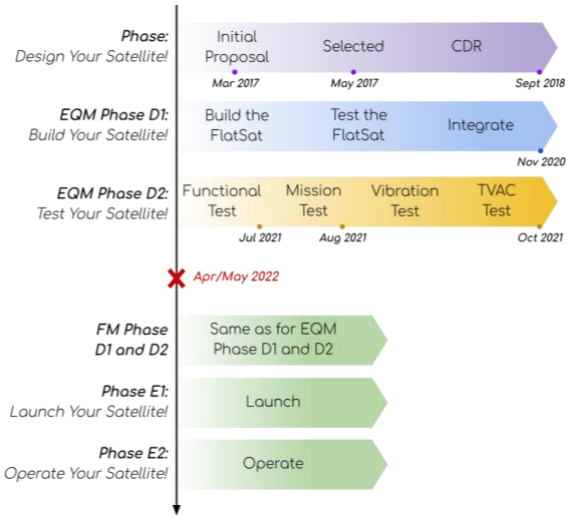

Figure 6. EIRSAT-1's project schedule.

In addition to EIRSAT-1, three other CubeSat teams are currently participating in FYS! 2 – LEDSAT, 3Cat-4 and ISTSat-1. LEDSAT was launched in August 2021 and is still in operation.

[3]Cat-4 and ISTSat-1 are in the process of preparing for launch in late-2022 [16].

5. Outreach & Dissemination

The EIRSAT-1 team primarily consists of students undertaking a masters or PhD at UCD as part of a module or as a more integral part of their degree, where the work forms part of their thesis. As a result, information on the project is regularly disseminated via conferences and publications (e.g., [1], see the list of references for further examples). However, as a key objective of EIRSAT-1 is to inspire the next generation of students towards the study of STEM subjects, to engage a wider audience, the team have additionally been involved in a broad range of outreach activities (Figure 7).

5.1. Talks

Team members frequently give talks at both primary and secondary level schools, as well as events, such as Space Week events. During the pandemic, these talks have continued virtually.

5.2. Social Media

In addition to the website (www.eirsat1.ie), updates on the status of the project and the team's activities are very regularly provided on social media, including Twitter, Facebook and Instagram (@EIRSAT1). This social media presence is demonstrated in Figure 7.

5.3. Informational Materials

The project has produced a range of engaging informational materials that are accessible to the public via the EIRSAT-1 website, including:

- A brochure: https://www.eirsat1.ie/post/eirsat-1-brochure
- A YouTube video: https://www.youtube.com/watch?v=EJqQdU4DNkY
- A comic book: https://www.eirsat1.ie/comicbook

5.4. Other

- *10 Things to Know About*

Throughout the project, EIRSAT-1 has gained attention from many national media outlets. For example, in addition to online and newspaper articles, EIRSAT-1 featured in '10 Things to Know About', a TV series produced by Ireland's national broadcaster.

- *Poetry and Art Competitions*

In 2021, the project led two interactive competitions aimed at students, focused on art and poetry. In both cases, students' works were showcased on EIRSAT-1's social media accounts. Additionally, submissions to the poetry initiative were also used to inspire a space-themed poem which will now be etched onto the FM of EIRSAT-1.

6. Conclusions

A status update on the EIRSAT-1 project is presented in this work, with a focus on the completion of an extensive EQM test campaign. Following this campaign, the project now advances to the FM, a significant step towards launch. Building on the outreach efforts presented, public engagement will continue to be essential to EIRSAT-1's objectives during the upcoming milestones, where future initiatives include, for example, a publicly accessible web portal in which live data from the spacecraft can be seen in real-time. Progression through some the project's most major milestones is expected over the coming months.

Figure 7. Examples of EIRSAT-1's outreach activities taken from the @EIRSAT1 social media accounts.

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References

[1] D. Murphy et al., "EIRSAT-1 – The Educational Irish Research Satellite", 2nd Symposium on Space Educational Activities, Budapest, Hungary, 11-12 April 2018.

[2] D. Murphy et al., "A compact instrument for gamma-ray burst detection on a CubeSat platform I", *Experimental Astronomy*, 52, 29-84, 2021.

[3] D. Murphy et al., "A compact instrument for gamma-ray burst detection on a CubeSat platform II", *Experimental Astronomy*, 2022.

[4] K. Doherty et al., "High-Temperature Solar Reflector Coating for the Solar Orbiter", *Journal of Spacecraft and Rockets*, 53, 1-8, 2016.

[5] K. Doherty et al., "Flat Absorber Coating for Spacecraft Thermal Control Applications", *Journal of Spacecraft and Rockets*, 53, 1035-1042, 2016.

[6] D. Sherwin et al., "Wave-based attitude control of EIRSAT-1, 2U CubeSat", 2nd Symposium on Space Educational Activities, Budapest, Hungary, 11-13 April 2018.

[7] J. Thompson et al., "Double-dipole antenna deployment system for EIRSAT-1, 2U CubeSat", 2nd Symposium on Space Educational Activities (SSEA), Budapest, Hungary, 11-13 April 2018.

[8] J. Reilly et al., "EIRFLAT-1: A FlatSat platform for the development and testing of 2U CubeSat EIRSAT-1", 4th Symposium on Space Educational Activities, Barcelona, Spain, 27-29 April 2022.

[9] A. Ulyanov et al., "Radiation damage study of SensL J-series silicon photomultipliers using 101.4 MeV protons", *Nuclear Instruments and Methods in Physics Research Section A*, 976, 164203, 2020

[10] ESA Article. Available Online: https://www.esa.int/Education/CubeSats_-_Fly_Your_Satellite/Student_CubeSats_undergo_testing_at_ESA_Academy_s_CubeSat_Support_Facility (Accessed on 25-02-2022)

[11] ESA Article. Available Online: https://www.esa.int/ESA_Multimedia/Images/2020/06/Testing_for_Ireland_s_first_satellite (Accessed on 25-02-2022)

[12] S. Walsh et al., "Development of the EIRSAT-1 CubeSat through Functional Verification of the Engineering Qualification Model", *Aerospace*, 8, 254, 2021

[13] M. Doyle et al., "Mission Test Campaign for the EIRSAT-1 Engineering Qualification Model", *Aerospace*, 9, 100, 2022

[14] ESA Article. Available Online: https://www.esa.int/Education/CubeSats_-_Fly_Your_Satellite/Towards_the_flight_model_EIRSAT-1_survives_an_intense_environmental_qualification_campaign (Accessed on 25-02-2022)

[15] R. Dunwoody et al., "Thermal Vacuum Test Campaign of the EIRSAT-1 Engineering Qualification Model", *Aerospace*, 9, 99, 2021

[16] ESA Article. Available Online: https://www.esa.int/Enabling_Support/Space_Transportation/Ariane/ESA_selects_payloads_for_Ariane_6_first_flight (Accessed on 25-02-2022)