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 activities are being undertaken to realise these aims.

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 mission, which is 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 goals are also being achieved with three novel payloads, known as GMOD [2, 3], EMOD [4] and WBC [5]. In addition to custom-built payloads, EIRSAT-1 (Figure 1), will fly an in-house developed antenna deployment module (ADM) [6] 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).

In this paper we provide an update on the status of the EIRSAT-1 project with particular emphasis on the EQM. Given the project's educational objectives, the team's outreach activities are also discussed. Finally, the remaining steps towards a 'ticket to launch' will be discussed. In addition to providing a project update, this work also gives 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, we note that the project timeline has been impacted by the COVID-19 pandemic as on-site working, travel and access to 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 [7], in which the satellite is assembled on a large motherboard or series of motherboards laid out horizontally.
Over the course of several months, the FlatSat was fully populated, as COTS components were received and acceptance tested, and as custom-built payloads were developed, tested and space qualified [8, 9, 10]. 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 [11].

2.2. EIRSAT-1

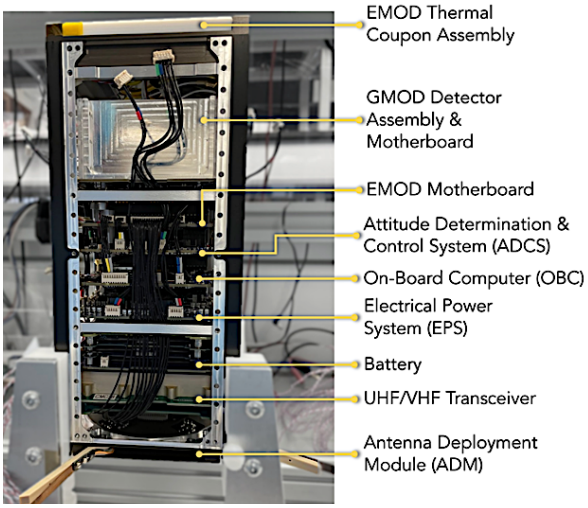

Figure 1. Stacked configuration of the EQM, showing EIRSAT-1's sub-systems and payloads.

In November 2020, the EQM components were 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 requirements, which were defined during CDR, and survive the extremes of spaceflight while doing so.

3.1. Ambient Testing

3.1.1. Functional Testing

Extensive, functional tests were carried out on the EQM, starting in December 2020 [11]. Unlike the FlatSat tests, full system-level functional testing is required by all teams within the FYS! 2 programme.

This testing continued until July 2021, longer than planned, due to four test anomalies (i.e., unexpected events that can 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 and its installation into the EQM stack, the relevant functional tests were repeated and passed [11].
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 and justified the model philosophy adopted, despite the additional time and resources required.

3.1.2. Mission Testing

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. 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.
The EQM mission test began in early August 2021 (Figure 2) and ran for 27 days continuously [12].

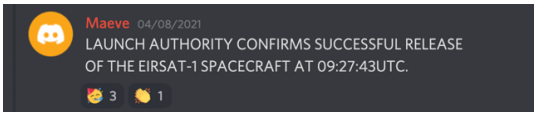

Figure 2. 'Launch' notification during EIRSAT-1's EQM mission testing.

Team members took on the role of 'spacecraft operator', acting within the constraints of real on-orbit operations (e.g., limited 2-way communication passes) 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. The EQM mission test was largely a success in terms of achieving the predefined test objectives. The team also gained valuable operations experience through the simulation [12].

3.2. Environmental Testing

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

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.

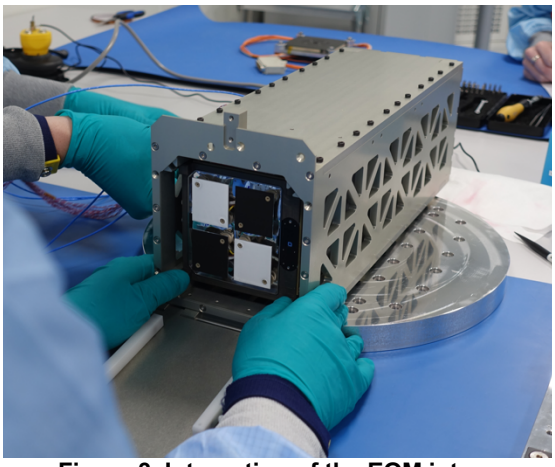

Figure 3. Integration of the EQM into a representative model of a CubeSat deployer.

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

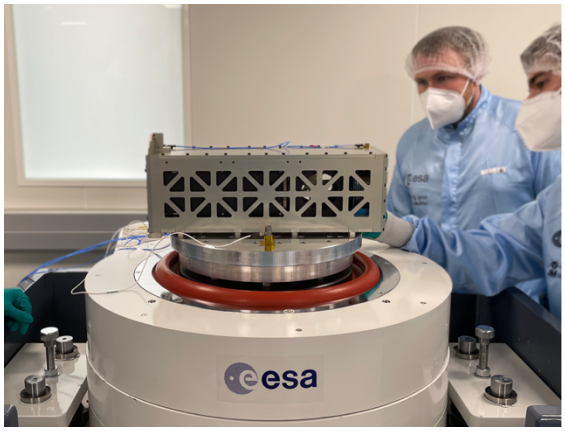

Figure 4. CubeSat deployer, containing the EQM, mounted on the shaker table.

Starting on 16th September, vibration tests were carried out, where each axis of the spacecraft was tested separately. Each axis experienced a random vibration level of 14g (RMS), exceeding those expected during launch of EIRSAT-1, for a period of ~2 minutes. This testing, which involved some data analysis as well as changes to the test set-up between axes, continued until 20th September, after which the EQM was removed from the test set-up and a health check performed.
The health check (essentially a reduced functional test that had also been completed

pre-test) proved that all critical subsystems (i.e. EPS, battery, OBC and radio) had survived the launch-like vibrations. The reduced functional test also revealed anomalous behaviour from the GMOD payload. On-site investigations suggested that some hardware damage to the payload was the likely cause of the observed behaviour (Section 4).

3.2.2. TVAC Testing

Although hardware damage to GMOD was suspected following vibration, the payload was still operational (e.g., it was capable of I2C communications with the OBC) 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.

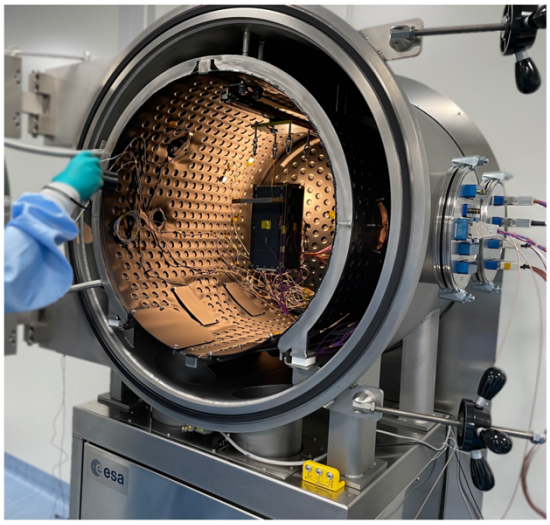

Figure 5. EQM integrated in the TVAC chamber.

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 powered on [14]. When powered on, health checks were performed to ensure all subsystems functioned nominally under TVAC conditions.

Excluding GMOD (for which 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 [14]. Crucially, the latter would likely not have been detected prior to launch without TVAC testing.

The EQM test campaign concluded on 15th October 2021 [13].

4. Road to Flight

Since concluding the EQM test campaign, the team's priority has been generating non-conformance reports (NCRs) which document anomalies experienced during 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 major NCR related to GMOD has required capacitors to be replaced and the provision of additional mechanical support following investigations which showed a capacitor solder joint was damaged during vibration testing. Once all NCRs are closed (or on track to close), the FM build will commence (Figure 6).

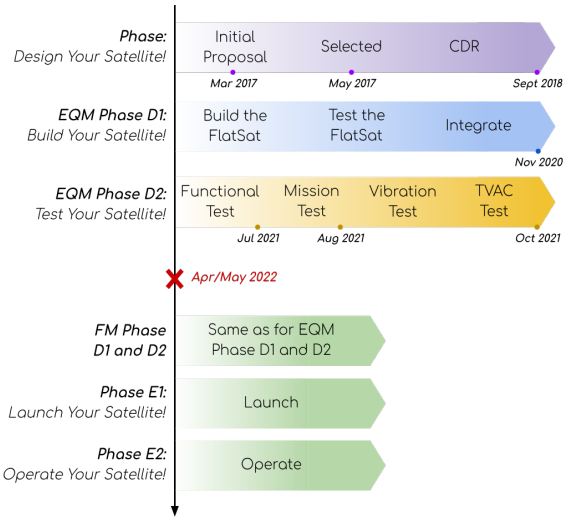

Figure 6. EIRSAT-1's project schedule.

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. 3Cat-4 and ISTSat-1 are in the process of preparing for launch in late-2022 [15].

5. Outreach & Dissemination

The EIRSAT-1 team primarily consists of students undertaking a masters or PhD, either as part of a module or as a more integral part of their degree, where the work forms part of their thesis. Information about the project is therefore

regularly disseminated via conferences and publications. Involving a wider audience beyond academia is a key objective of EIRSAT-1. Not only do we want to inspire the next generation of students towards the study of STEM, but we also emphasise the key message that space is for everyone. The team has therefore undertaken a broad range of outreach activities (Figure 7) [16].

5.1. Talks

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

5.2. Social Media

Updates on the status of the project and the team's activities are provided on the website (www.eirsat1.ie) and on social media, including Twitter, Facebook and Instagram (@EIRSAT1).

5.3. Informational Materials

The project has produced a range of engaging informational materials that are available on the EIRSAT-1 website, including:

- A brochure describing the team and their backgrounds for use during National Space Week careers roadshows for secondary school students: https://www.eirsat1.ie/post/eirsat-1-brochure
- A YouTube video: https://www.youtube.com/watch?v=EJqQdU4DNkY
- A comic book for 9-10 year olds that has been distributed to every primary school in Ireland: 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, RTE.

- *Space Poem and Space Art Challenge*

In 2021, two online outreach activities were held, aimed at secondary school students, and focused on art and poetry. In both cases, students' creative works were showcased on the EIRSAT-1 social media accounts. The space poem was co-created by school pupils from diverse backgrounds, in collaboration with the JCSP library demonstration project, UCD creative writers and the Museum of Literature Ireland. The space-themed poem, called 'All Ways Home', will be etched onto the EIRSAT-1 FM.

6. Conclusions

Following the EQM test campaign, the project now advances to the FM, a significant step towards launch. Building on the outreach efforts, public engagement will continue to be a major feature during the upcoming milestones.

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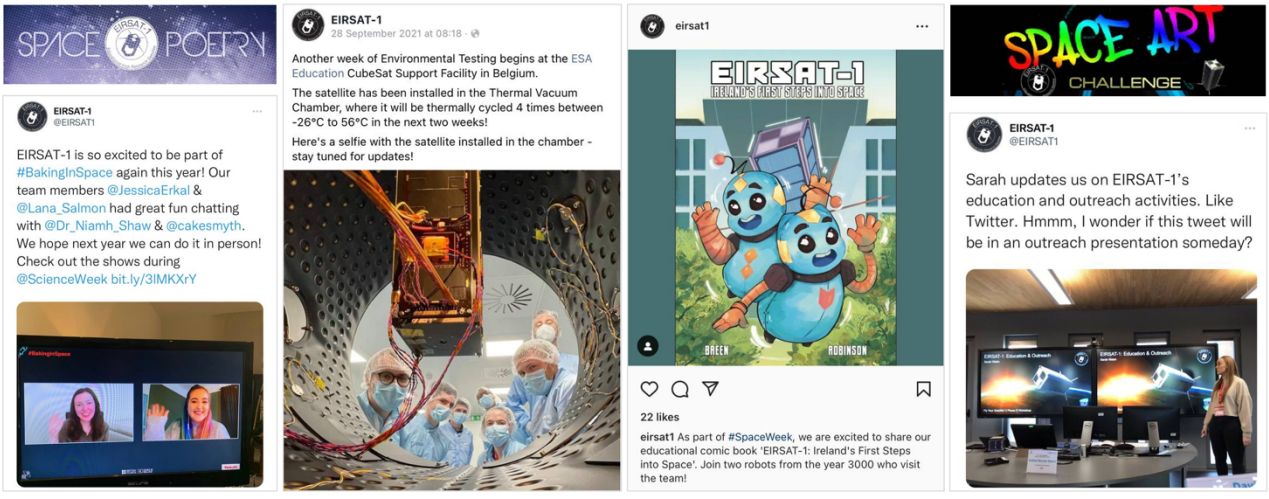

Figure 7. Examples of EIRSAT-1's outreach activities taken from the @EIRSAT1 social media accounts.

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