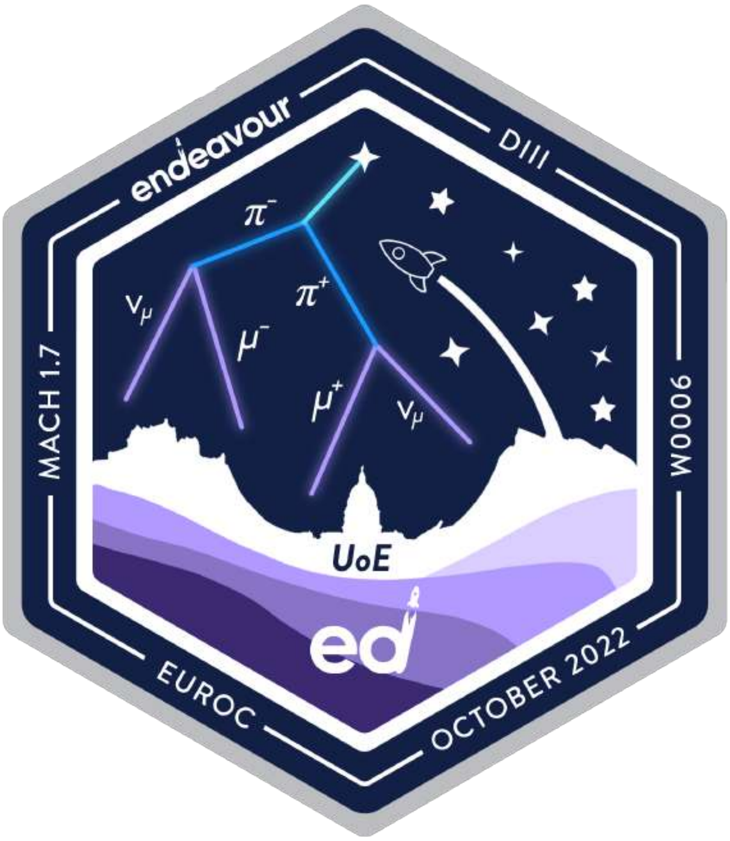
Darwin III: Lessons Learned

Team 11 Post-Flight Analysis for the 2022 EuRoC



17 October 2022

1 — Press Release

Saturday 15th of October, 2022, the Darwin III launch vehicle, which was conceptualised, designed and manufactured by the endeavour student group based in Edinburgh, took off on its flight to 9000 meters from the Santa Margarida Army Base in Portugal during the European Rocketry Challenge launch campaign. The launch vehicle was carrying a payload featuring two scientifically significant experiments, which were recognised by the European Space Agency Payload Award as the best out of the over 20 experiments presented by the teams competing in the competition.

Figure 1.1: Computer Aided Design (CAD) model of the Darwin III Launch Vehicle with Fin-Can Detail.

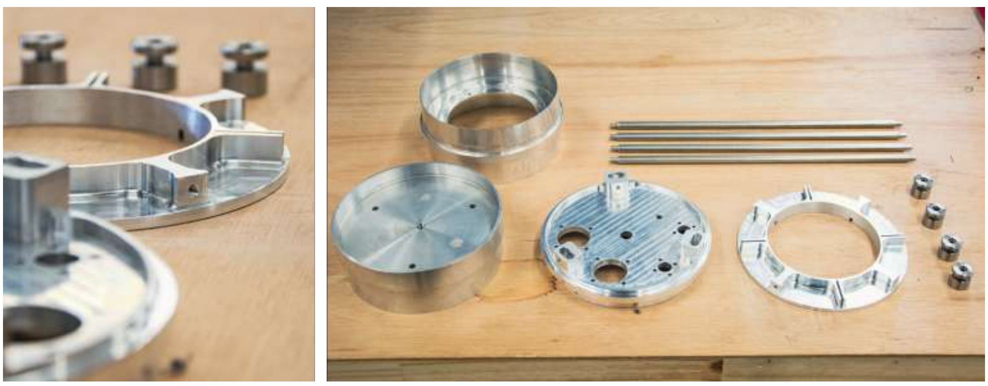


Figure 1.2: Wholly student-designed CNC Machined Bulkheads and Structural rods which support the Carbon Fiber airframe. Machined at the University of Edinburgh Mechanical Engineering Machine Shop in Sanderson Building.

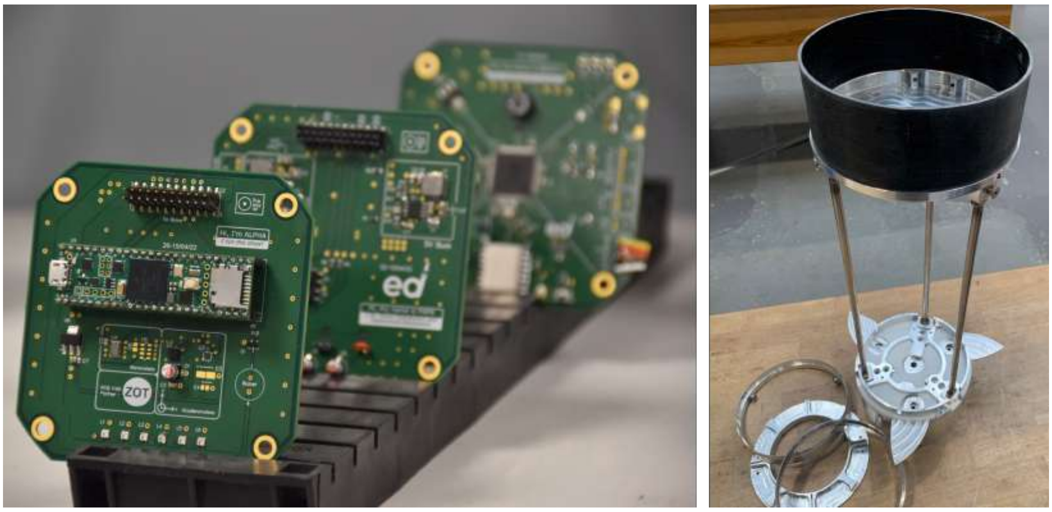


Figure 1.3: Three of the over 10 student designed and assembled Printed Circuit Boards (PCBs) comprising the Avionics Stack responisble for datalogging, guidance and telemetry tasks

Figure 1.4: Images of the Team taken at the Unveiling Event held at the Informatics Forum in the University of Edinburgh Central Area Campus.

The launch team is composed by the following students from the Schools of Engineering, Informatics and Physics from the University of Edinburgh.

Name	**Role**
Alberto Progida	Flight Director (FIDO)
Zsolt Csonka	Integration Lead
Thomas Stott	SRAD Avionics Deputy
Ann Lee	Logistics Lead
Daniel Holler	Software Lead
Alex Stevenson	Recovery Lead
Jo Shepton	Payload Principal Investigator (PI)
Virginia Cangelosi	Payload Electrical Lead
Matus Komjaty	Ground Station Operator (GSO1)
Joseph Azrak	Ground Station Operator (GSO2)
Jasper Day	Structures Deputy
Phil Heinrich	Payload Software Deputy
Fergus Wilson	Payload Mechanical Deputy

The Payload

The experiments are a student built muon detector (a modified version of MIT's CosmicWatch Muon Detector, adapted and ruggedized to survive the harsh launch environement) and a fluid dynamics slosh experiment. The mission aims the payload were as follows:

1. Collect muon count data using our modified CosmicWatch muon detector during flight to explore how muon detection rate changes with altitude, along with correlating it to temperature and pressure data the payload collects independently
2. Compare the muon rate during flight to the rate at sea level to explore Einstein's theory of special relativity and the efficiency of the detector
3. Using a wide-angle lens camera, observe how propylene glycol (a fluid with a higher viscosity than water) behaves during flight and how this relates to the wave fluid dynamics, with focus on the potential points of micro-gravity.
4. Using the IMU acceleration data, attempt to reproduce the recorded fluid behaviour in a Computational Fluid Dynamics (CFD) simulation.

Both of these experiments have been researched extensively and characterised during a Summer Internship conducted in collaboration with the School of Physics focusing on testing the limits of the muon detector.

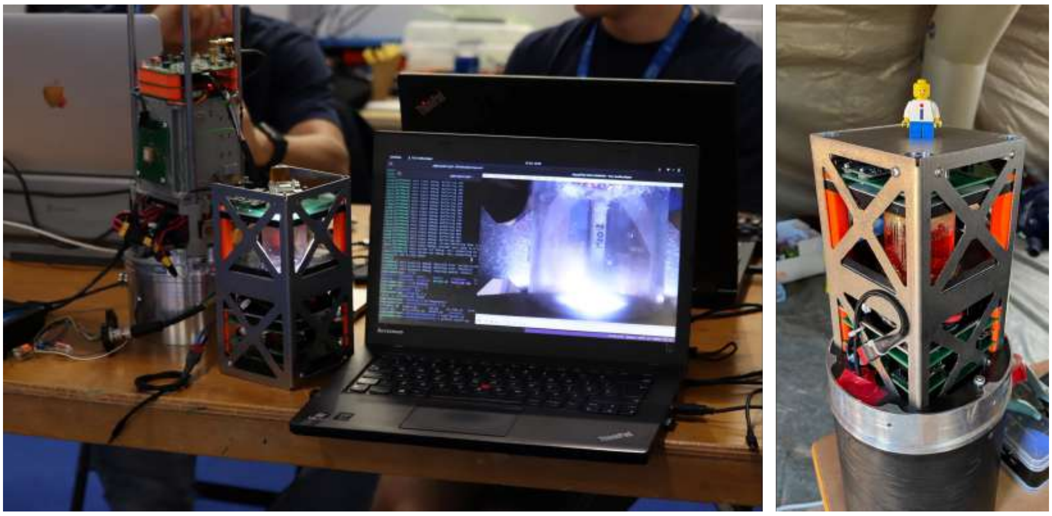


Figure 1.5: A fully integrated test of the Avionics and Payload, while streaming video data to a host PC (left). The payload being fully integrated with the airframe at the Launch Site Integration Tent

The Launch

Powered by a Cesaroni Technologies Inc. (CTI) O3400 solid rocket motor, the 34.334kg vehicle took off the pad, performing a nominal 6.2 second burn. The structure, manufactured by students at the University facilities out of high performance Carbon Fiber Reinforced Polymer (CFRP) composites and high-strength 7075-T6 Aluminium alloy withstood the 500kg thrust load imparted by the motor, cutting through the dense atmosphere while accelerating at 150m/s2. Ignition had been attempted with the manufacturer-provided igniter the previous day, 14/10/22 at 17:10 GMT, but had failed due to the humidity at the launchsite. A more energetic igniter was installed on launch day, and the propulsive reaction began successfully at 12:00:28 GMT.

Takeoff was detected by the Student Researched and Developed (SRAD) Avionics stack, but telemetry was lost prematurely due to the high interference environment and high speed. The team's Ground Station Operators (GSO2) maintained contact with the Commercial Off-The-Shelf tracking beacon throughout the launch preparation procedures and the initial phases of flight. Tracking was temporarily lost at motor burnout due to the high altitude and velocities, making it challenging to manually point the High Gain antennas at

Figure 1.6: Final assembly of the 4 Main Segments in the Integration Tent

Figure 1.7: The journey of Darwin III from the Integration Tent to the Launch Pad

the vehicle.

Figure 1.8: Liftoff and the long boosting phase captured by the official ESA photographer. The plume consists mostly of water vapour and some CO_2. The Team is currently developing a "green" bi-liquid engine with 95% combustion efficiency and a significantly cleaner exhaust

20 seconds into the flight, one of the two GSO's briefly regained contact with COTS transceiver, confirming the avionics had survived the expected initial 15G (150m/s2) acceleration. Both Mission Control and the Spectator Area report a sonic boom seconds early in the boost phase, which is consistent with the trajectory simulations carried out by the Team. GPS coordinates were not received due to the vehicle's supersonic

speed, which deactivated in accordance with the Coordinating Committee for Multilateral Export Controls (CoCoM) regulations on GPS-equipped airborne objects. Following a chirp confirming the avionics health, contact was lost again and no further telemetry was received by the Endeavour Mission Control. EuRoC Mission Control maintained more precise tracking and managed to receive a single GPS coordinate once the vehicle had exited the supersonic regime, confirming the vehicle had crossed the point of maximum aerodynamic pressure (MAX-Q) without losing structural integrity. The vehicle ascended remarkably straight - a testament to the stiffness of the team's structure and the accuracy of the fin construction.

Figure 1.9: The Misison Control team (left) and the Setup of the Ground Stations (right)

Further attempts to re-establish a telemetry link failed as the vehicle disappeared into the high-altitude haze slowly shedding velocity. No data is available from here-on, and events are based on educated estimations informed by the flight characteristics and trajectory simulations executed ahead of flight.

Visual confirmation of drogue or main parachute ejection was not given, and the vehicle was assumed ballistic. No damage to life, limb or property was recorded and no fires were reported. Two recovery teams were dispatched immediately after the closing of the launch window to the last GPS coordinates received, which were necessarily in close proximity to the launch site due the early flight-stage in which they were received. The recovery crews were not immediately succesful but were later directed towards a point at 39.386377N, -8.275252W by a local fire brigade, where Darwin III was immediately identified in a "lawn dart" position in the shade of some large trees.

Figure 1.10: The Landing Site of DIII and images from the Team Debriefing

The vehicle failed to deploy its nosecone at apogee, thus entering a high velocity dive quickly reaching its terminal velocity of 251m/s. Darwin continued its descent following a ballistic trajectory, finally impacting the ground and penetrating approximately 600mm into the Portuguese soil, a dry mixture of gravel, sand and mid-sized sharp rocks, releasing 724'000 joules of energy in 8 thousands of a second.

80% of the vehicle disintegrated on impact, with failure modes ranging from brittle explosion, to plastic deformation, composite delamination and buckling. The aft end of the lower body, including the fins and the thrust structure, was recovered nearly intact, except for evidence of violent impact on the fins most likely attributable to the forest canopy. There is little evidence of delamination caused by aero-thermal heating, and few fatigue cracks imputable to fin flutter. Every system of the vehicle has been recovered and catalogued, but the vehicle is cannot be reflown in its current state.

Figure 1.11: The Remains of Darwin III, exhibited to theJury for the Post-Flight Review. The root cause identified by the Team and confirmed as highly likely by the Technical Experts.

Overall 4 out of the 6 goals set by the team were achieved, making the mission a partial success despite the off-nominal recovery phase. On the technical side, the team was able to validate several manufacturing techniques and prove the robustness of the structure through the most aggressive flight stages - notably the fins, nosecone and interstages. The student-developed avionics performed nominally, but the deployment on the field highlighted some areas for improvement, namely transmission power. Despite the data from the payload not being recoverable, its scientific basis was recognised by the European Space Agency, building confidence in the team's rigorous processes in areas outside of manufacturing and engineering and strengthening ties to the UoE School of Physics. On the operational side, massive leaps in organisation and integration between subsystems was achieved, yielding a vehicle which could be assembled in under 30 minutes in the inhospitable desert environment. The focus on health and safety, checklists and procedures resulted in an overall reliable and predictable vehicle to operate and launch.

The team is extremely grateful to the stakeholders who have made all of this possible: our primary academic partner (Schools of Engineering, Physics, Chemistry and Informatics at the University of Edinburgh), our main industrial partners (MCarbo, supplier of CFRP airframe; ZOT, supplier of Printed Circuit Boards; Dassault Systemes, Altium and nTopology, suppliers of professional-grade software), our sponsors (Skyrora, Edinburgh Innovations, Data Driven Innovation and EasyComposites). Finally, a heartfelt "obrigado" goes to the incredibly welcoming and flexible team of EuRoC for providing the regulatory, organisational and logistical support that enables the launch of such high-performance vehicles.

Figure 1.12: An imaage of the Launch Team following the Awards' Ceremony

Figure 1.13: The Logos of our generous sponsors and industrial partners.

The Post-Flight Analysis

The **Motor Casing** plastically deformed on impact, splaying outwards and tearing open, with the Forward Closure becoming one with the Motor Bulkhead and the Motor Retention Hardware. The Motor Tube features evidence of extreme delamination following the winding angle pattern.

The 8mm thick Stainless Steel Force Rods supporting the **Avionics Bay** were found contorted upon themselves, having ripped their housing blocks from the Motor and Recovery Bulkheads respectively. This is evidence of the immense shear loading experienced on impact, sufficient to shear off over 3cm2 of 7075-T6 Aluminium.

The **Avionics** was flattened amongst the bulkheads and most Surface Mounted Devices (SMD) such as passive components and power regulators were ripped off the boards by the force of impact. The team is happy to report that a FLASH chip was salveaged from the COTS Quantum Flight Computer in good conditions. Data recovery attempts will be made in a controlled laboratory environment upon the return to Edinburgh.

The **Recovery system components** were in a range of condutions. The compliant parachutes only present some small perforations, while the recovery hardware such as the SRAD mechanism and the COTS Tender

Descenders and Raptor systems were severaly damaged.

The **Payload** was flattened between its two heavy bulkheads, with the avionics encapsulated within the steel and aluminium sheets. No data storage devices were salvaged, with all 3 SD cards haveing been found in a fractured state. The Payload and the Nosecone and Nosecone Tip were found at the bottom of the hole created by the vehicle, suggesting lack of separation at Apogee.