DESIGN CHALLENGES, AND OUTCOMES OF BUILDING A SATELLITE THE SIZE OF A SODA CAN

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Abstract

A Mach contest is part of an annual event, organized by UKLSL, which combines both CanSat and rocket competitions. The first Mach event in 2021 was focused on the design of "Simple and Advance CanSats", and culminated on a 3-day activity at Machrihanish Airbase in Scotland. It involved setup, pre-flight checks, and system adjustments. This paper focuses on the design challenges, and outcomes from building a satellite the size of a soda can by reviewing the event, the mission designed for the competition, and students' feedback on what could have been improved to prepare the next team competing in Mach-22 which would involve developing a Rocket design and launching an "Advance CanSat".

The competition allowed undergraduate students at The University of Nottingham to experience a practical learning style by solving real engineering problems and practicing professional development skills through design review presentations and providing a flight readiness review to the launch providers of the competition. The proposed mission statement was part of the "PEAK" category, which involved atmospheric studies, where it acts as a simulation model for measuring the atmosphere on different planets and as a deployable probe from rovers to measure varying atmospheric levels. The competition exposed students to perform AITV (Assembly, Integration, Testing, Verification) processes to their CanSat and constructed procedures to test and validate the recovery system. Results from the first Mach event prove a solid starting point for future CanSat competition and space activities within our university. In the future, there are aspirations to grow a student space society and get students involved in extra-curricular STEM (Science, Technology, Engineering, Math) projects, and allow them to apply the theory and concepts learned in their academics.

Keywords

CanSat, Space Education, Mach-21, Mission design, Spacecraft systems and instruments

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Acronyms/Abbreviations

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

C&DH	*Command and Data Handling*
COTS	*Customer Off-The-Shelf*
MCU	*Micro-Controller Unit*
SNARC	*South Nottingham Amateur Radio Club*
TT&C	*Telemetry, Tracking, and Command*

1. Introduction

During Mach-21event, University of Nottingham entered for the first time on a CanSat competition [2]. The event was hosted by UKLSL at the Machrihanish Airbase [1] and supported by Gravitilab Aerospace Services, which provided the launch opportunity.

The main driver of entering the competition was to apply concepts discussed in lectures and develop more hands-on activities such as circuit design and programming using a Micro-Controller Unit (MCU).

The team consisted of a pair of undergraduate students studying Aerospace Engineering who aimed to design and manufacture a small satellite the size of the soda can. The team called UON-ADCP (University of Nottingham–Atmosphere Data Collection Probe), was supported by staff member from Department of Mechanical, Materials and Manufacturing Engineering and developed the project as an extra-curricular activity.

The lessons learned from this project gave a baseline for the next competition Mach-22, where the new team would develop an advance CanSat released by its own designed rocket at an altitude close to 1km. In contrast, the CanSat entered for Mach-21 was designed to be ejected at an altitude between 500-700km.

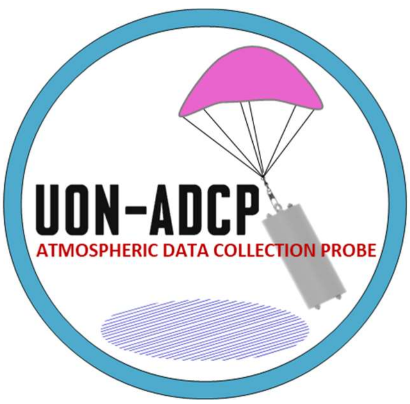

Figure 1. UON-ADCP Logo

1.1. Timeline

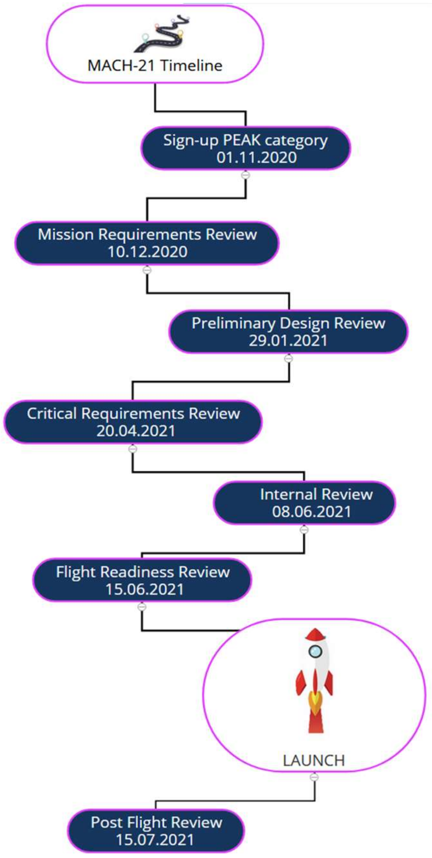

Figure 2: MACH-21 timeline

Figure 2 shows MACH-21 project timeline emphasizing the main project phases and review. The project provided all teams an opportunity to have a 1-1 meeting as feedback for the Critical Design Review (CDR) stage thanks to the involvement of Gravitilab Aerospace, which was called at that time Raptor Aerospace. They also scheduled a virtual seminar with all the teams to highlight testing procedures to consider for the Flight Readiness Review (FRR). In addition, they provided the option to use a standardized CanSat shell to ensure two PEAK CanSat payloads would fit inside their rocket. These solutions and support were extremely useful for the developer team that had the opportunity to have feedback and suggestions to implement the quality of the proposed system.

2. Objectives and Aims

2.1. Mission Profile

An outline of the mission profile can be seen in Figure 3. The CanSat would undergo pre-flight checks a day before the launch, which would involve checking the all the system of the CanSat are in operation. On the day of the launch, it would be integrated in the rocket by Gravitilabs Aerospace. After, launch and ejection phases, the CanSat would descent with a passive parachute deployment and send GPS data for CanSat retrieval.

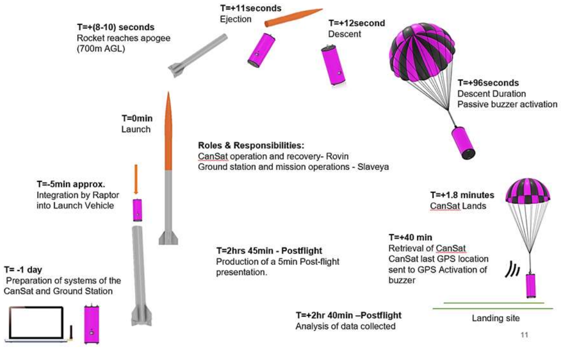

Figure 3:Mission profile diagram for ADCP CanSat

2.2. *Aims*

The CanSat's mission was to collect information about the air pollution around the launch site (and chart comparison to Nottingham, where the team was based) and to track its flight path in real-time.

During the competition, the team had an opportunity to gain practical experience in electronics, material selection, mechanical design, manufacture, and full system testing.

2.3. *CanSat launch objectives*

Considering the declared mission statement the CanSat:

- act as a simulation model for measuring the atmosphere on different planets.
- act as a probe for rovers or spacecraft in orbit to measure atmosphere levels.

The main mission requirements can be condensate in

- Use onboard sensors to measure atmospheric data
- Transmit Live telemetry to the ground station
- Be able to recover CanSat using GPS and buzzer to locate

The established mission success criteria are:

- Collect atmospheric data
- Collect temperature and pressure data
- Transmit live data to ground station
- Descent and landing – no mechanical or electrical damages to the CanSat

2.4. *CanSat overall mission objective*

The main overall mission objective for this project was to gain hands-on experience with using electronics and applying spacecraft systems and design methods on a practical project. Moreover, the team followed the ESA design processes on developing a satellite, covering the design review stages required.

3. CanSat Design

3.1. Science Payload

The payload of the CanSat to measure temperature, pressure, and atmospheric data to compare the results at two locations, primarily in Nottingham and at Scotland.

To achieve this goal, the following sensors *where selected* (Table 1):

Table 1: Sensor modules overview

Altimeter Module MS5607	Temperature range: -40 to +85°C with <0.1°C resolution
	Pressure range: 10-1200 mbar
Air Quality Click 5 Sensor Module	Contains RED, OX and NH3 sensor
	Measures carbon monoxide (CO), nitrogen dioxide (NO2), ethanol (C2H5OH), hydrogen (H2), ammonia (NH3), methane (CH4), propane (C3H8), and isobutane (C4H10)
Adafruit Industries 746 GPS	Position accuracy: 3m
	165dBm sensitivity
	Internal storage

3.2. *Electrical System*

Figure 4 shows the block diagram of the UON-ADCP CanSat electrical system. It consists of a master power switch, two alkaline batteries, voltage regulators for voltage regulation of the two main power lines (3.3V and 5V) and a LED for power indication.

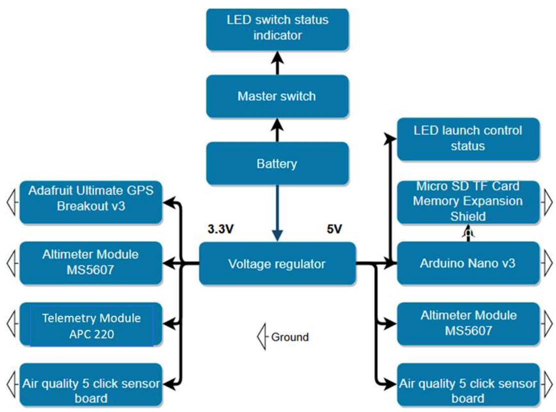

Figure 4: Electrical system layout block diagram

3.2.1. *Programming*

The CanSat used an Arduino MCU and Arduino IDE to write and develop the program for the CanSat BUS.

3.2.2. *Data Transmitting*

To remotely collect the data, a radio module was used to send telemetry down to a portable ground station which consisted of an APC220

radio module. The CanSat was able to transmit sensor data to the ground station.
The team conducted testing of the module set-up to ensure the telemetry could be verified.

3.3. Structures and Mechanisms

An exploded view of the CanSat structure can be seen in Figure 5. It has been produced using 3DExperience CAD software.

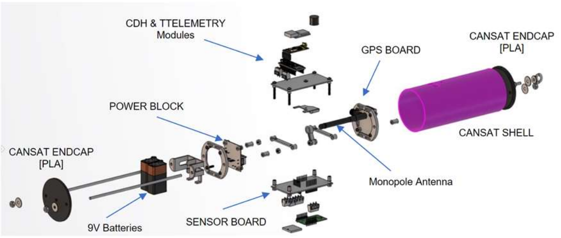

Figure 5: Exploded view CanSat structure

3.4. Recovery System

The recovery system is a critical element of the design because the system would be responsible for ensuring the data can be retrieved if the ground segment of the mission fails to collect any data. The system also has a set requirement to have a 10m/s descent rate and not to drift 500m from the launch site.

3.4.1. Parachute Sizing

UON-ADCP recovery system features the use of COTS (Customer Off-The-Shelf) parachutes from BlackCat Rocketry which included a bridle swivel and shock cord. The size of the parachute was selected based on the estimated descent rate it would provide as shown in Table 2 2. The result of this would be used to calculate the kinetic energy it would experience during impact.

Table 2 2: Calculated Descent Rate Estimates

Descent rate (m/s)	Area (m^2)	Diameter (in)	Comment
13.121	0.0506	10	Very High
10.931	0.0729	12	High
7.284	0.1642	18	Selected

3.4.2. Estimate Wind Drift

To predict the landing site of the CanSat, wind drift estimates were performed to ensure the operation of the CanSat is within the confines of the airbase.

Figure 6: Landing Site Estimates - Launch Pad A and B locations in Red. In Pink dashed lines shows the effect of wind drift and shows landing region.

4. Design review Stages

4.1. Mission Requirement Review (MRR)

Mission Selection was determined on the analogy to follow the rule of KISS (Keep It Simple Stupid). The primary role of the mission review is to determine the selected payload for the CanSat. Ensure a more robust solution was decided to maximize the chances of a successful mission.

4.2. Preliminary Design Review (PDR)

At PDR, a conceptual design was completed, sensors were selected, and a preliminary layout of the components was selected for all subsystems. At the PDR stage, a damping system with springs was planned to be developed to protect the electronics from the shock load and vibrations during launch.

4.3. Critical Design Review (CDR)

Before the CDR stage, it was decided a complex damping system was not required.

The telemetry module was also changed from the Onethinx OTX-18PSoC®6xLoRaWAN module to the APC 220 due to procurement issues.

At the CDR stage, most of the components had been ordered, the recovery system and internal structure had been fully designed, and the manufacturing process and the electrical configuration had been fully defined.

4.4. Flight Readiness Review (FRR)

At the FRR stage, the CanSat was fully compliant with the competition requirements.
Testing performed included waterproofing test, visibility test, drop tests, battery performance and environment testing (in hot +30C and cold -10C conditions), and sensor testing. The telemetry and the altimeter calibration had yet to be done.

4.5. *Post-Flight Review*

After the recovery of the CanSat, the team analysed the data and produced a document

4.5.1. Data collected

The system was able to perform the first phase of the mission, where atmospheric data was collected at Nottingham several days before the launch event.

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MICS-6814 Sensor Sample
Calibrating SensorOK!
NH3: 578/559 = 1.08 => 0.58ppm
CO: 589/584 = 1.05 => 4.01ppm
NO2: 608/584 = 1.13 => 0.17ppm
NH3: 622/559 = 1.30 => 0.43ppm
CO: 627/584 = 1.22 => 3.38ppm
NO2: 642/584 = 1.28 => 0.19ppm
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Figure 7: Atmospheric sensor results sample - Nottingham

4.5.2. *Structural* damages

Post-flight the CanSat was inspected for structural damages. Two main issues were found. The GPS breadboard was heavily damaged (see Figure 8), although the testing revealed the GPS module itself survived the impact.

The bottom endcaps, which should have protected the batteries, failed and they had taken significant damage (see Figure 9) which could have compromised the safety on-site. The root cause of the problem was the material selected for the endcaps as it was unable to take the +60G impact from the piston ejection of the rocket.

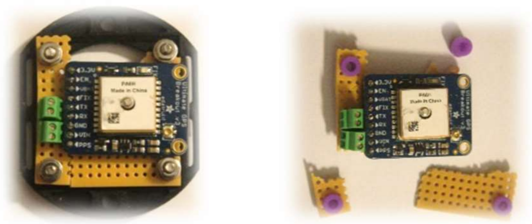

Figure 8: Post-flight damage on GPS board

Figure 9: Post-flight damage to the batteries

4.5.3. Other issues

Telemetry bus had an issue in connecting on launch day and the team decided that the system would not have the radio module during launch and would only store the data collected on an SD card connected to the Arduino.

5. Design Challenges

5.1. Risk assessment and mitigation at FRR

Potential points of failure have been carefully considered and steps have been taken to eliminate them, where possible, and mitigate them if not.
Table 2 is a summary of the risk assessment undertaken.

Table 33: Risk assessment and mitigation

Failure Mode	Part	Cause	Effect	Mitigation
Critical failure	Sensors	Water damage	Incorrect/ no reading	Waterproofing the switch and LED gap with parafilm
	Power block	Water damage	Short circuit	Waterproofing the switch and LED gap with parafilm
	Power block	Wires disconnected or exposed wires connected	Short circuit/ Sensors not reading	Wire terminals and silicon glue for insulation
	Power switch	Wires disconnected	Power off	Strong connection, silicon insulation and shock test
	Battery	Battery running out	Not enough power for operation	Two parallel 9V batteries and battery performance test
	Parachute	Parachute fails to open/ disconnect from CanSat	Screw unscrewed/ parachute attachment breakage	Loctite thread locker and drop test
Critical/non-critical failure (depending on the severity)	Buzzer	Buzzer not activated/ too quiet	Difficult recovery	Passive buzzer; disconnect tested
	SD card disconnect	Shock on deployment/ landing	No backup memory storage	Glue to the shield module and shock test
Non-critical	GPS backup battery disconnect	Shock on deployment/ landing	No backup power for the GPS	Silicon glue and shock/ drop test

5.2. Internal layout of the electronics

The internal layout has been iterated multiple times throughout the design stages to optimise the CanSat BUS and the structural design. The biggest challenge was obtaining the CAD files from the COTS vendors, which impacted the chosen layout of the electronics and mechanical interfaces inside the CanSat.

6. Discussion and Results

6.1. Lessons learned

6.1.1. Procurement

Using COTS components usually have fluctuating delivery times, which is important to consider because this can delay or stall the project's progress.

Bring and order spare parts and components during the development of the engineering and flight model because this is critical to mitigating the risk and delays of the project. Moreover, it would be useful if all major parts come from the same suppliers for easier integration.

6.1.2. Power distribution

More reverse voltage protection (diodes) and resistors to smooth out current was required to protect the microcontroller and sensors, and to ensure the data collected was not affected by current irregularity.

6.1.3. Software development

The team would suggest working in GitHub, or a similar hosting platform to allow past versions of the software to be logged and tracked because it would be more efficient to track changes made on multiple programmes.

6.1.4. Testing

Comprehensive testing after the CDR is critical in the development of a full Flight Model (FM). The team experienced several issues with its FM at the launch event in Scotland. To resolve them, the functionality of the flat sat model was verified on-site, the CanSat subsystems were assembled and then tested again. The test of the fully assembled systems revealed that it was not storing the data consistently.

A stack testing would need to be performed for future missions because this area was highlighted as the main reason it failed to record data at the launch event.

Ensure the (FM) Flight Model and (EM) Engineering Model are at a stage of completion and procedures have been conducted.

6.1.5. Management

Ensuring the management of the project was found to be a critical factor to ensure the success of the project. For example, the number of iterations for the electronics configuration was developed until the final FM was produced.

The team learned that the design must be frozen just after the CDR to allow for thorough testing and verification of the electronics and portable ground station.

Based on Akin's 3rd Law of Spacecraft design, the number of iterations should be "One more than the number you have currently done" [3]

Lastly, documentation of system developments was critical because this would allow a hand-over procedure to take place and keep records of the project as teams complete their undergraduate studies.

6.2. Overall mission result

The team considers the mission as a success ending up with an overall 3rd place in the competition in both categories and finished 2nd place in the PEAK category which consisted of the marks received on the design review stages for developing a simple CanSat architecture.

The team is also aware that several improvements can be done to optimize the system and its working on that for the future competition.

7. Conclusions

The project has found that there is a huge benefit in tackling hand-on activities outside lecture-based projects. It has allowed the students to develop new practical skills such as soldering, creating bread-board models to test their circuit designs, and project management. An extremely useful part was for sure the assembly, integration, test and verification phase for the mission.

The results the team has achieved have encouraged more students to participate in Mach-22 where a combined entry of an advance CanSat and Rocket is being developed.

Acknowledgements

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