Team Zephyr

FINAL DESIGN REPORT

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Abstract

Miniature satellite flights have long sought to emulate the missions of orbital experiments, yet have all lacked one critical component: precise attitude control. Each CanSat launched is at the mercy of the wind and air, without the fine control characteristic of industry satellites. Thus, in the RotaSat project, Team Zephyr aimed to develop a fully-featured, modular satellite system capable of active attitude control and an assortment of ground control modules. This was done through the miniaturisation of techniques used by satellites currently in operation, from the orientation tracking system to the reaction control hardware. An Arduino-based custom flight computer was developed alongside state machine control software and active-control hardware, all designed to scale. Together, these three major components emulate the methods used in the aerospace industry. The particular RotaSat configuration meant to fly at the Bologna launch event was designed to emulate an earth-imaging satellite. Initial ground tests showed an excellent response time of 0.81s for the reaction wheel to recover the satellite's orientation from a large offset. System integration tests showed the satellite's systems working harmoniously with the modular ground station, which confirmed the operation of a fully-featured miniature can-sized satellite and its supporting hardware and software. RotaSat in its current state is able to serve as the basis of any advanced CanSat, with its modular design and plentitude of features, and eventually as the first template of an orbital SmallSat.

I INTRODUCTION

The mission of RotaSat was trifold. The first and foremost goal is to verify the design of the first CanSat template. RotaSat has a modular design, and the main objective was to test that design throughout powered ascent, descent, and recovery. The configuration chosen to fly is based on systems of an earth observation satellite, with active attitude control systems and a high-resolution camera. Having control authority over the craft is integral to every orbital satellite, and the aim was to be able to take this technology and scale it down as a module on RotaSat.

The RotaSat project aimed to develop a fully-featured, modular satellite system capable of active attitude control and the capability of multiple mission configurations. RotaSat utilises a sensor suite consisting of an inertial measurement unit (IMU), a high-G accelerometer unit, barometer, thermometer, GPS, and a 4K camera capable of simultaneous streaming and recording. Comprehensive data was to be collected from all sensors and analysed in a variety of ways, from 3D trajectory plotting to visual identifications of landmarks. As RotaSat's flight was a technical demonstration, it needed to verify the modularity of the design, specifically the reaction control system, which used the first aluminium reaction wheel flown on a CanSat. The team expected high-definition and rotationally smooth video to be recovered as part of a successful mission. Additionally, a new camera component sled was flown on RotaSat's second flight (post-nationals) to further demonstrate its versatility.

II PROJECT DESCRIPTION

II.I Mission Outline

The RotaSat mission was to design and construct a miniature satellite to be flown to a height of approximately 1 kilometre. As the satellite ascended with the rocket, it was to record the rocket's flight data as an extended primary mission. Once separated from the rocket, the CanSat needed to descend at a rate of 8 (±1) metres per second, while transmitting its full data package at 15Hz. It was to activate and run its reaction control wheel system until saturation or landing, which would be reflected in the recorded and streamed video. The CanSat was to be recovered by the development team through GPS and video data post-flight.

The intention of this final report is to summarise the design process, specifications, mission, and flight of Team Zephyr's RotaSat CanSat.

Goal	Criteria	Importance
Structural Stability of Modular Design	The satellite remains fully operational and intact throughout launch, descent, and landing.	High
Data Transmission	At least 70% of flight data is sent throughout the launch and landing of the satellite, at different rates depending on the stage of the mission.	High
Active Roll Stabilisation	Orientation on the X axis deviates by no more than ±15° while the reaction control wheel is active.	High
Descent Rate	The satellite descends at a rate between 7 and 9 metres per second.	Medium
Recovery	The satellite is found and recovered through GPS and video data after flight.	Medium
Rocket Data Logging	The satellite records IMU and barometric data of the rocket launch.	Low

Table I: Mission Outline

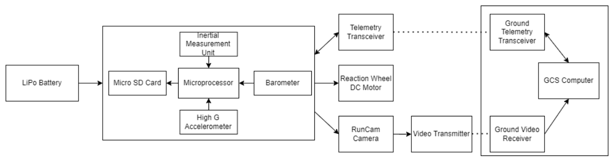

Fig. I: Block Diagram

II.II Hardware Design

The CanSat was designed to be 65 millimetres in diameter and 107 millimetres in height. The GPS, telemetry, and video transmission antennae extends 36.5 millimetres above the top of the satellite, sharing space with the parachute hardware.

II.II.I Methodology

To design this satellite, concepts applied in the large-scale industry were researched and understood. To miniaturise them, commercial alternatives or custom designs are used according to the aforementioned standards. In order to meet the objectives in a short timeframe, iterative development was employed; multiple revisions of hardware and software designs were created, tested, analysed, and then improved upon, in accordance with part testing, simulation, and flight data.

II.II.II Structure

The airframe was based on a “tri-fold” layout with modular mounts for different component sleds. The entire airframe is enclosed by a specially fitted translucent 3D print printed in PVB filament processed with isopropyl alcohol for foriegn object protection. The case was made in two halves for easy disassembly for access to the internal components. The structure consists of two 3D-printed plates with mounting points for the component sleds, as well as slots for the carbon fibre rods as the backbone of the structure.

To verify the aerodynamics of the design, the entire airframe was taken into Ansys Fluent, where a Computational Fluid Dynamic simulation (Fig. II) was performed to observe drag and stability characteristics for better optimization of the reaction control wheel system.

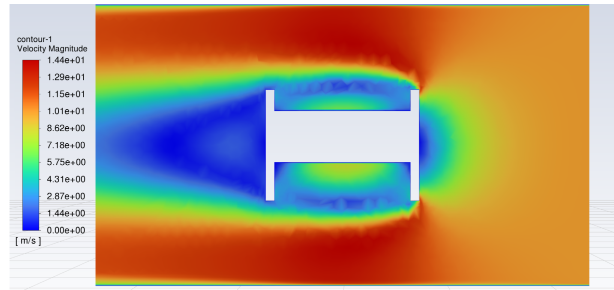

Fig. II: Computational fluid analysis of the CanSat structure at the planned descent velocity.

The goal of RotaSat was to be a modular system, and this particular system uses four main components. The component sleds are secured to the frame by M3x6 screws to embedded inserts in the 3D print, while the modular reaction control system is attached through eight standoffs. Diagrams below.

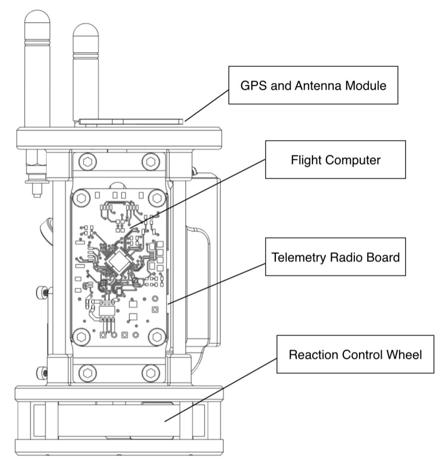

Fig. III*:* The Avionics Sled is a modular and critical component of the design. Used to mount the majority of the CanSat electronics, the current implementation on RotaSat utilises four brass 6mm standoffs to mount the flight computer above the telemetry radio board.

A 31g eight-spoke aluminium reaction control wheel was designed by Team Zephyr and manufactured by Modern Engineering in Delta, BC, Canada on a 5-axis mill.

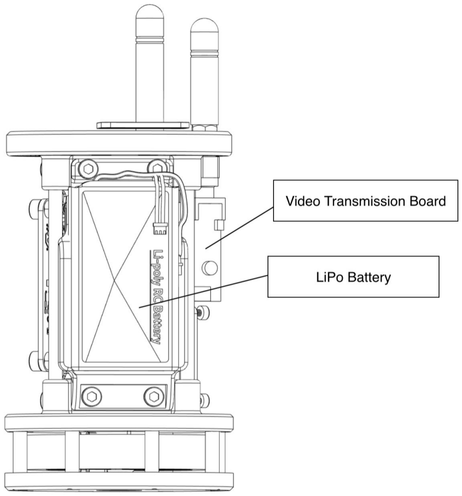

Fig. IV: The Video Transmission Board (VTX) is located near the side, mounted into the top plate and slotting into the Camera Sled.

The Power Sled is the mount for the lithium-polymer battery that powers the electronics systems of the CanSat. This sled can be modified to take different batteries to power an assortment of different flight computers.

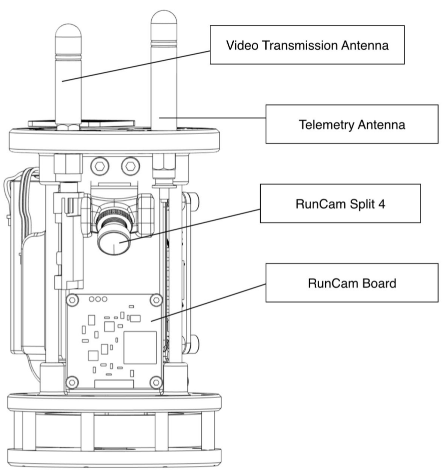

Fig. V: The Camera Sled is a modular component of RotaSat's structure. The lens of the Runcam Split 4 is mounted on the sled, alongside its control board. This is the mission module that could be exchanged for an ultrasonic sensor or an extended atmospheric sensor package on other missions.

Mounted above the Camera Sled on the top plate are the transmission antennas, with one transmitting at 5.8GHz, and another at 433MHz. These are for the live video and telemetry transmission, respectively.

II.III Avionics Design

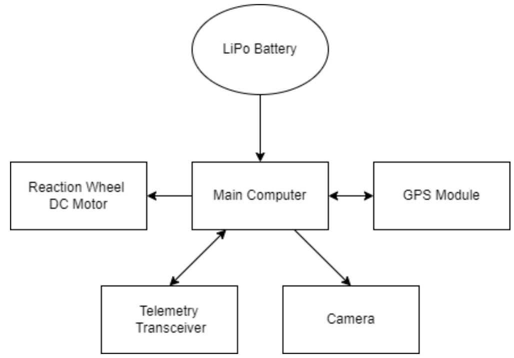

Fig. VI: RotaSat avionics diagram

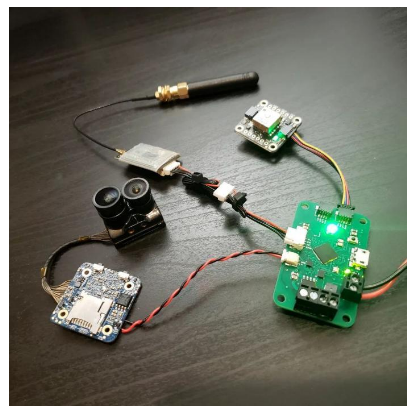

Fig. VII: RotaSat's full avionics system powered on

II.III.I On-Board Computer

The on-board computer (Fig. IX) is a single, proprietary board designed specifically for this mission. The computer is a 50mm x 30mm x 1.6mm, 4 layer PCB designed in Autodesk Eagle (Fig. VIII) and manufactured by JLCPCB. The outer copper layers are 1oz, inner layers are 0.5oz. The layer stack-up is Signal, GND, Power/Signal, Signal.

The Atmel ATSAMD21G18 is a high performance, ARM Cortex M0+ based processor. This microcontroller was selected for its high flash memory, processing power and GPIO pins.

The changes between the Revision 1, Revision 2 and Revision 3 computers are a more appropriate choice of buck converter IC (considering the global semiconductor shortage), improved footprints for the IMU, High G Accelerometer Unit, the Barometer, and the addition of a MOSFET to safely drive the buzzer at its full current draw of 90mA.

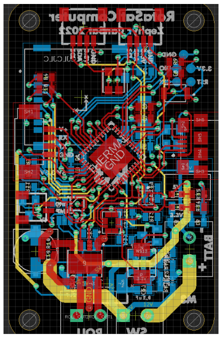

Fig. VIII: Fully routed R3 computer

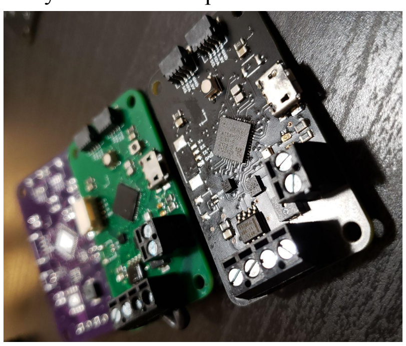

Fig. IX: R1 (left), R2 (centre) and R3 (right) computers

II.III.II Power System

The power system (Fig. X) was designed with the maximum current draw of each major electrical component taken into consideration. A 900mAh rechargeable 2 cell Lithium Polymer (LiPo) battery was selected for its appropriate current capacity, its nominal voltage of 7.4V, and high energy density. Post master switch, 7.4V is powering the RunCam Split 4 and the DC Motor for the reaction wheel. To step down from 7.4V to 5V, a 3A synchronous buck converter is used. The telemetry transceiver is powered with 5V. The Advanced Analog Circuits AZ1117H 1A linear regulator is used to regulate 5V to 3.3V. The main computer runs on 3.3V logic. The sensors, SD Card and GPS Receiver are powered with 3.3V.

A CR1220 3V Real Time Clock (RTC) coin cell battery was connected to the GPS receiver module, allowing "warm starts" of the GPS receiver, which give us lower time to first fix (TTFF).

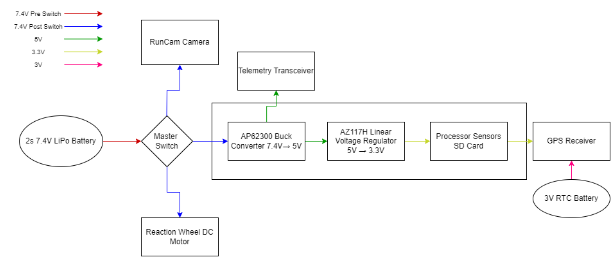

Fig. X: RotaSat's power system

II.III.III Recovery Electronics

The Adafruit PA1010D GNSS module is used to receive geographic coordinates from satellites in the GPS, GLONASS, GALILEO and QZSS constellations. The module was selected for its low current draw (30mA), 10Hz update rate, built-in patch antenna, its I2C capability and accuracy of ±3.00 metres.

For close range recovery, the CUI Devices CMT-4023S magnetic buzzer was selected for its small package dimensions (4mm x 4mm x 2mm), 4kHz maximum frequency and decibel level of 70dB.

II.III.IV Payloads

The Bosch BMP388 was selected as the pressure and temperature sensor for its high accuracy and low sensor noise. This sensor has pressure accuracy of ±0.08 hPa and temperature accuracy of ±0.5 °C. The pressure data can be used to estimate altitude to ±0.5 m using the hypsometric formula (Eq.1). Communications are done over I2C.

$$Hypsometric\ formula$$

$$h = \frac{\left(\left(\frac{P_0}{P}\right)^{\frac{1}{5.257}} - 1\right) \times (T + 273.15)}{0.0065} \qquad [1]$$

The STMicroelectronics LSM6DS3TR-C IMU contains three low G accelerometers (±16G Maximum Range), three gyroscopes (±2000°/s Maximum Range), and a temperature sensor. This IMU was selected for its low initial sensor biases and high robustness to mechanical shock. The data from this IMU was recorded and transmitted, the temperature data used as a secondary temperature datapoint. Communications were over I2C.

The Rohm Semiconductor KX134 accelerometer unit is included to measure acceleration in all three axes during the peak Gs of the launch vehicle's powered ascent. This accelerometer unit was selected because of its high maximum acceleration range of ±64G. This ensures RotaSat can launch on a wide selection of launch vehicles while still recording accurate data. Communications are over I2C.

The mRobotics SiK telemetry transceivers on 433mHz are used for communications with RotaSat. The transceiver on the satellite is connected to a 0dBi 433mHz whip antenna. Communications are done over Serial using TTL at 3.3V.

A Micro SD card is used to store flight data in a comma-separated values (.csv) file. Communications with the Micro SD card are done over SPI.

All inertial sensors on RotaSat's flight computer are oriented so X is roll, Y is pitch and Z is yaw, matching RotaSat's coordinate system.

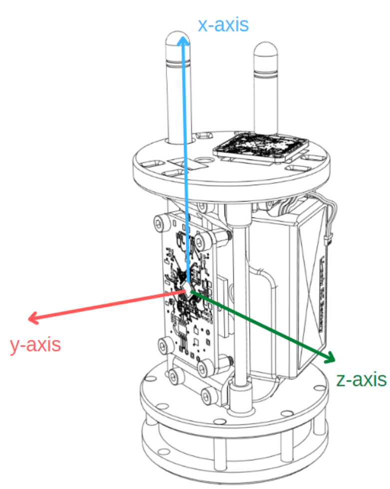

Fig. XI: RotaSat's coordinate system

The reaction wheel is driven by a brushed DC motor. Testing showed that with the reaction wheel, the motor exerted the necessary control authority to orient RotaSat. The DC motor is driven by a DRV8871 H-Bridge IC. This IC was selected because of the built-in current regulation and the ability to feed it 2 3.3V PWM signals to control speed and direction.

A RunCam Split 4 Camera is mounted on RotaSat to capture 2.7K 60fps video, in flight. The RunCam was powered using 7.4V through a dedicated connector on the flight computer. A MOSFET circuit is used to switch the power supplied to the RunCam, allowing manual commands from the GCS (3.1) or triggers programmed into the state machine software (II.IV.I) to power the RunCam on/off. This helps to conserve power by limiting current draw only to phases of RotaSat's mission where video recording is necessary. An AKK X2 video transmission board is connected to the RunCam to transmit video signals. Data was sent over a 2.8 dBi antenna.

II.IV Software Design

RotaSat's flight software is programmed in C++ using the PlatformIO extension for Visual Studio Code. The source code is stored on a remote Git repository, enabling multiple group members to work on the project simultaneously. The code is separated into different files based on function, which reduces merge conflicts, decreases compilation time, and allows for easier unit testing. Files were programmed to be modular, allowing code to be repurposed in other Arduino projects with minimal changes. The ground control station was written in Java, using the Processing IDE.

II.IV.I State Machine

The software is structured as a finite state machine (Fig. XII), similar to the ones used on many satellites, or space launch vehicles such as SpaceX's Falcon 9 and NASA's Space Launch System. On power up, RotaSat switches to the "Avionics Error" state if any components fail to initialise correctly. Otherwise, RotaSat defaults to the "Ground Idle" state.

When RotaSat receives a specific command from the ground station, it will switch to the launch ready state, where RotaSat undergoes gyro debiasing and increases its transmitting frequency to 15Hz. During this state, RotaSat will use gravity to determine its orientation, and look for a spike in acceleration over a short period of time or continual increase in altitude to switch to the "Powered Ascent" state. RotaSat's camera is either powered on manually by a ground station command, or at the beginning of the "Powered Ascent" state.

After RotaSat reaches apogee, it switches into the "Parachute Descent" state, which transitions into the "Roll Control" state after a five second timer. During this stage, RotaSat uses the reaction control wheel to stabilise the roll axis attitude. At 50m AGL, RotaSat goes into the "Landing Detect" state, which disables the reaction control wheel to prevent any spikes in current draw from the vibrations of landing. After detecting landing, RotaSat goes into the "Mission Complete" state, which disables the camera and reduces the logging rate to 1Hz to conserve battery power. RotaSat also indicates its current state using the on-board LED and buzzer.

Fig. XII: RotaSat's states and state exit conditions

II.IV.II Data Estimate

Rotasat is expected to transmit approximately 200 KB of telemetry data during descent. The same amount of data will be logged into the on-board micro SD card. The CanSat will also record around 700 MB of footage to an on-board SD card and stream approximately 300 MB of it.

II.V Recovery System

The main recovery method of RotaSat is by parachute descent. The parachute is a 45 cm thin-mill nylon chute with a 12.5 cm spill hole in the centre (Fig. XIII) to provide better stability and reduce wear on the outer edges of the parachute at higher velocities. It is attached to the satellite through two quicklinks, one connected to the parachute cords and another connected to the 4-millimetre paracord looped through three mounting points on RotaSat's top plate. The parachute quicklink and the satellite quicklink are joined by an M5 rotating pin, lubricated with silicone to allow for easy operation of the reaction control system.

The targeted descent rate is 8 metres per second, and the expected descent time from one kilometre will be two minutes and five seconds. To ensure recovery after landing, the aforementioned GPS system and live visualizer, as well as live-streamed video (described in III.IV), will be utilised during the search.

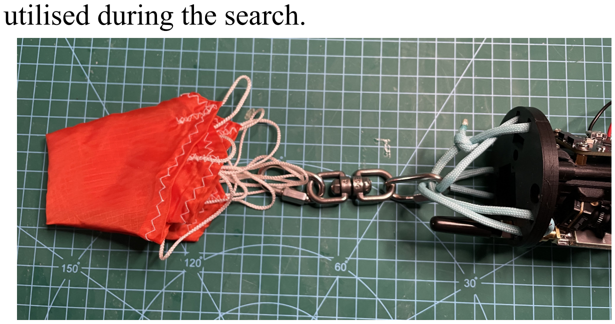

Fig. XIII: RotaSat's Parachute

III GROUND SUPPORT EQUIPMENT

The ground station consisted of a directional yagi antenna (4.3) connected to a 433mHz transceiver module. Received telemetry data was sent to a laptop over a serial connection. Telemetry strings were read by three independent software programs: Ground Control Station (GCS) with Live GPS Mapping, Text-to-Speech program, and Backup Data Logging software. To enable simultaneous access to the data stream coming from the satellite, a "Serial Splitter" software was used to replicate the data in an accessible format for the three programs. As a whole, the ground station was a system to monitor RotaSat during its mission, and sent manual commands when necessary. Refer to the ground control system diagram (Fig. XIV).

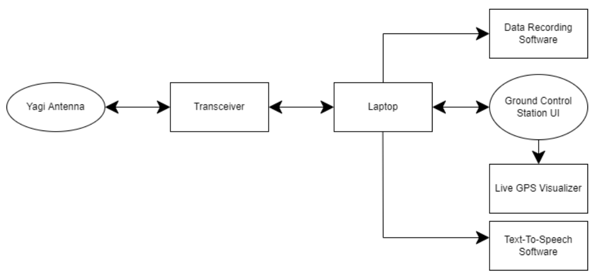

Fig. XIV: The Ground Control System

III.I GCS Software

The RotaSat Ground Control Station (GCS) is a user interface written in Java. The GCS reads telemetry strings through a 115200 baud Serial COM port (Fig. XV). After verifying the string is complete and valid, the parsed data is displayed on screen as graphs and raw data (Fig. XVI). To avoid displaying any invalid data, the first 7 bytes of a received string are checked against a preset prefix (ROTATLM). Following that, the number of datapoints in the string is checked to match with the expected length. Commands from ground to RotaSat can be sent through the GCS. The technology is essential to the mission, as well as demonstrating two-way telecommunications, a critical function of every orbital satellite.

Fig. XV: The RotaSat Ground Control

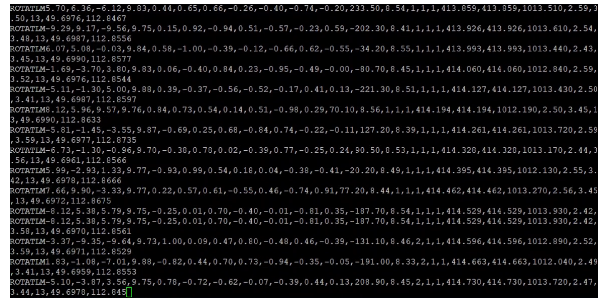

Fig.XVI: Raw telemetry strings received Station (GCS) over serial

III.II Visualisation Software

A live GPS tracking visualizer was written and integrated with the GCS software to display the satellite's location in real-time. The program received and parsed the telemetry string inputs to isolate latitude and longitude values. Utilising the giCentre Utilities library, the location and trajectory of the satellite were mapped. The visualizer clearly verifies the validity of the data being received. Furthermore, this feature is congruous with the mission of providing safe and optimal recovery.

III.III Ground Station Antenna

Being the backbone for communication between the GCS and the satellite, the ground station antenna's functionality was crucial to the mission's success. The antenna the GCS used is a 5 element yagi-uda antenna with a 9dBi gain, which was chosen due to its increased signal gain towards the front. FPV footage was to be transmitted using the 5.8GHz band, and was received by a triple feed patch antenna with a gain of 9.4dBi. For data transmission between RotaSat and the ground station, the team used 433 MHz and 5.8 GHz.

III.IV Live Video Transmission

RotaSat was to transmit onboard video during flight, serving as a useful tool for on-site analysis of the flight and as a recovery tool. A series of components were used to record, convert, and transmit the flight video during descent. Video transmission was received through a patch antenna on the ground, which was connected to a UVC OTG receiver that converted the video to a signal that is readable by video capture software on the computer. This had the dual effect of both showing live video and recording it, in case the satellite was not recovered.

III.V Text-To-Speech Software

Text-to-speech software was also intended to be implemented with the GCS. Utilizing MaryTTS, an online speech synthesiser library written using Java, the program received various points of data from telemetry via the serial splitter and converted this to speech. It would have provided essential auditory information such as the altitude and state of the satellite, but was deprioritized and eventually removed from the final GCS plan due to other pressing issues.

III.V Data Filtering

As RotaSat logs all data that it collects during flight, certain pieces of information sent to telemetry was fragmentary. This resulted in a .csv file consisting of both complete and incomplete data which was difficult to sort through during post-flight data analysis. To address this problem, a data filtering program was created to be activated once the CanSat enters its recovery state. Immediately after landing, the program sorted through all data received by telemetry, reading the original .csv file and creating a new one comprising only complete data. This not only speeded up the analysis process but also allowed the team to evaluate the amount of quality data collected throughout the mission.

IV CANSAT SPECIFICATIONS

IV.I Maximum Expected Power Consumption:

The table below shows the peak current draw and power consumption during the flight. Conserving battery power was a major consideration in our avionics design process. High consumption components of our avionics system (RunCam, DC Motor, VTX) were designed to be powered on and off throughout the duration of the mission, both autonomously through software, and manually through the GCS.

During the pre-launch and recovery portions of the mission, the maximum current draw was 0.100A. The flight battery's capacity was 0.900Ah; the maximum time RotaSat can be powered on in idle state is 9 hours. The actual operation time during a full mission will approximately be 7.37 hours, as the flight will consume 162.5mAh. However, this total is an underestimate, as the power calculations are done with theoretical peak draws.

Idle Phase

Item Name	**Voltage (V)**	**Current (A)**	**Power (W)**
GPS Module	3.3V	0.030A	0.099W
Telemetry Transmit Radio	5.0V	0.030A	0.099W
High G Accelerometer	3.3V	0.0001A	0.00033W
Inertial Measurement Unit	3.3V	0.001A	0.0033W
Barometer	3.3V	0.0 05A	0.0165W
Processor	3.3V	0.010A	0.033W
LED	3.3V	0.050A	0.165W
Total:		0.100A	0.419W

Table III: Power Budget during Idle Phase

In-Flight Phase (2 minutes and 5 seconds)

Item Name	**Voltage (V)**	**Current (A)**	**Power (W)**
Pre/Post Flight	Variable	0.100A	0.419W
RunCam Split 4	7.4V	0.650A	4.81W
Reaction Wheel Motor	7.4V	3.6A	26.64W
Video Transmitter Module	7.4V	0.200A	1.48W
Micro SD Card	3.3V	0.100A	0.330W
Total:		4.68A	33.66W

Table IV: Power Budget during In-Flight Phase

IV.II CanSat Characteristics Specification

Characteristics	Figure (units)
Height of the CanSat	107mm
Mass of the CanSat	315g
Diameter of the CanSat	65.1mm
Additional length of external elements (along axial dimension)	36.5mm
Flight time scheduled	125 seconds
Calculated descent rate	8m/s
Radio frequency used	433.00MHz
Power consumption	0.100A (idle)
Total cost	€363.72

Table V: CanSat Characteristics Specifications

IV.III Budget

Item Name	Price
GPS Module	$51.90
2S 900mAh LiPo Battery	$12.50
Telemetry Transmit Antenna	$12.50
Reaction Control Wheel & Motor	$50.00
SiK Telemetry Radios	$79.11
Flight Computer	$80.00
Parachutes	$11.60
Parachute Attachment Hardware	$15.00
Runcam Split 4	$115.49
Mechanical Fastener Hardware	$15.00
Video Transmitter Module	$23.99
Video Transmitter Antenna	$10.49
3D Printed CanSat Structure	$1.86
Carbon Fibre Rod	$10.00
Total CAD:	$489.98
Total EUR:	€363.72

Table II: Budget

IV.III.I External support

After reaching out to multiple companies to support our mission, we have received both monetary and non-monetary aid. EarthDaily Analytics, Iridian Spectral Technologies, Virogin Biotech, Deploy Solutions, GHGSat, and Modern Engineering provided sponsorships, while JLCPCB and AllRockets provided PCBs and the parachute. However, we lacked the expertise and assistance of a teacher or mentor, as RotaSat is a passion project of the team supported by parents.

IV.IV Testing Plan

IV.IV.I Parachute Drop Test

A parachute drop test was conducted at Burnaby Lake Park using a drone and a proxy CanSat weighing 343 grams. The stand-in was released at an altitude of 50 metres, and an approximate speed was calculated. In the end, the satellite fell at approximately 10m/s, which was over the desired result of 8m/s. As well, the drop exhibited “cupping” motion, with the parachute spilling air and losing structural integrity. This decreased the stability of the flight. As such, RotaSat utilised a larger parachute with a spill hole.

IV.IV.II GPS Accuracy Testing

To assess the accuracy of the satellite’s real-time location, the latitude and longitude obtained from RotaSat’s telemetry string was validated against the actual coordinates of the test location. The resulting difference was within 1 metres, so the accuracy of data transmitted for the primary mission and the satellite’s location for recovery after landing was considered a mission success.

IV.IV.III Range Testing

During the Canadian CanSat Design Challenge, it became apparent that the 5.4dbi gain of the moxon antenna used was not adequate for long-range telemetry. The new ground station antenna was tested to 250 metres, but a full test was never conducted.

IV.IV.IV Software Testing

Thorough software testing was essential in ensuring RotaSat functions properly during launch. RotaSat's modular code allowed for easy unit testing, which was rigorously conducted on all written code to ensure functionality, before implementation in the state machine. Additionally, extensive system testing was performed on the RotaSat to ensure all components of the software function as expected.

IV.IV.V Reaction Control System Test

The reaction control wheel was simultaneously tuned and tested together. It was tuned through physical loop testing using the Zeigler-Nichols method, and this also verified the level of control authority the RCS had over the vehicle.

IV.IV.VI Total System Integration Test

The final verification of RotaSat was planned to be a full mock flight from 100 metres. The satellite would be connected to the fully-featured ground control system with mapping and read-outs enabled, and flown with the final flight firmware loaded. All systems of the CanSat, from GPS to reaction control to data collection, were to be activated in flight. However, due to the discovery of multiple emergency electronic failures with the camera and the MOSFET that powered it, the secondary mission's integrity was prioritised over testing.

V MISSION RESULTS

The RotaSat mission was overall partially successful. The Primary mission was completed successfully, 81KB of data was received over telemetry downlink. A clear correlation between pressure, temperature and altitude is shown in Fig. XXI; as altitude increases, pressure and temperature decrease. An additional 22 datapoints were also successfully transmitted for our extended primary mission objective. 3D visualisation of RotaSat's flight trajectory using GPS coordinate and altitude data is shown in Fig. XVI. The Secondary mission was partially completed as only one of three objectives were successfully demonstrated. The modular design of RotaSat was successfully verified, however the reaction wheel and the video capture/streaming systems did not function in flight.

Fig. XVII: 3D Visualization of RotaSat's Flight Trajectory

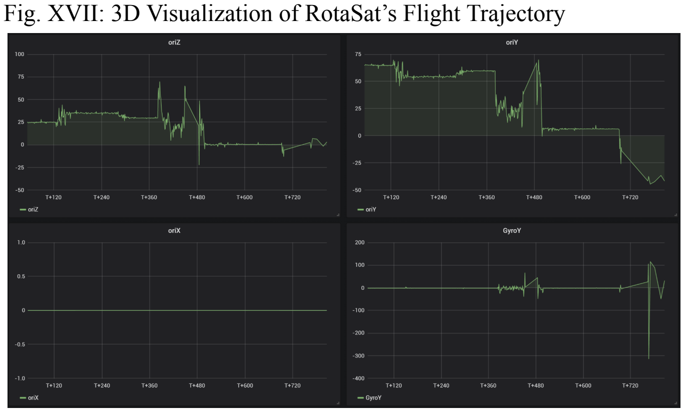

Fig. XVIII: X,Y,Z Axis Attitude and Y Axis Angular Rate

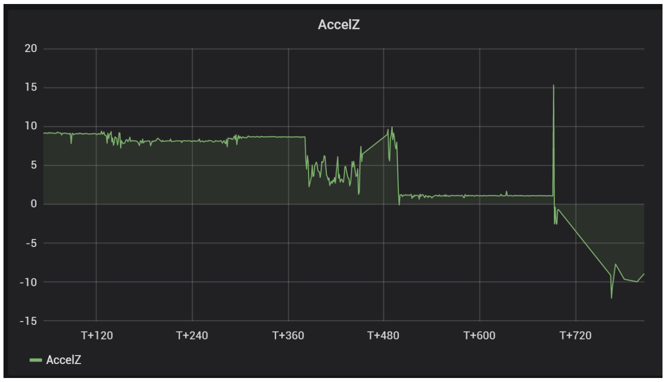

Fig. XIX: Z Axis Acceleration Data

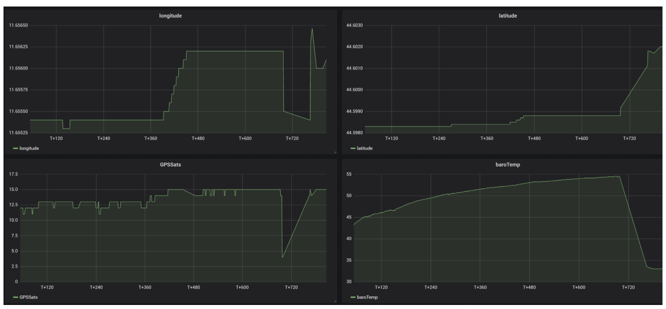

Fig. XX: Latitude, Longitude, Satellite Count and Temperature

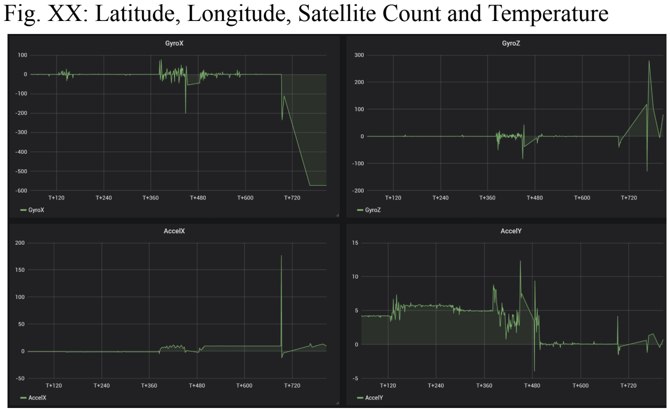

Fig. XXI: X,Z axis angular rate and X,Y acceleration data

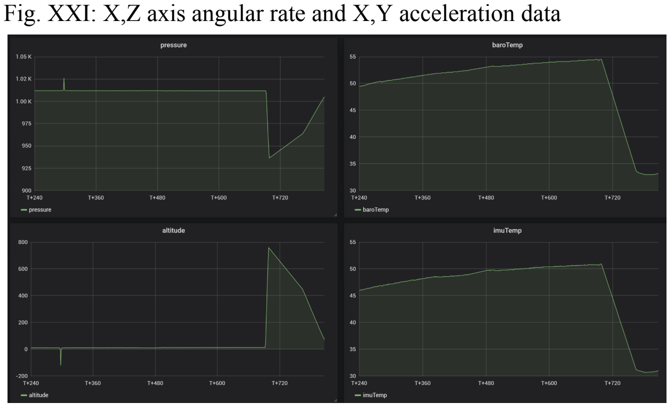

Fig. XXII: Temperature, Altitude and Pressure Data

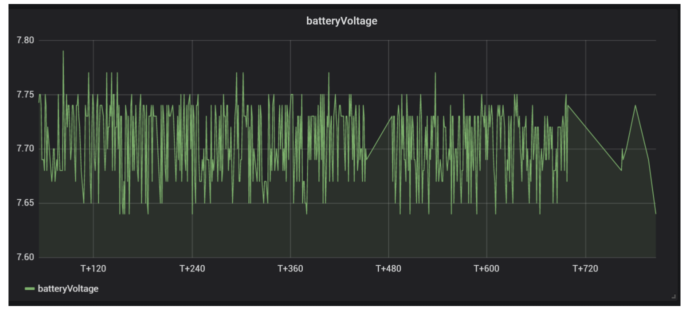

Fig. XXIII: Battery Voltage Data

VI DISCUSSION

The results of the ESA launch campaign were mixed for RotaSat. During launch, members failed to manually engage the flight states of the satellite, and as a result, much of the secondary mission was unsuccessful. The telemetry data received, although complete, is inaccurate in several data points due to the flight state. The orientation data is flawed, due to measurements being calculated from the accelerometers rather than the gyroscopes on the ground to determine initial attitude. However, this is easily solved due to the available gyroscope measurements, which is able to be used to recreate orientation during flight. The other, more pressing issue is the scarcity of data received. During ascent and descent, sixteen packets of data, approximately 2KB, were received. This was sufficient to locate the landing spot within a metre's accuracy, as the GPS worked flawlessly, but is an issue that compromises the higher level data collection abilities of RotaSat.

The diagnosis for this flight was that the yagi antenna used was a broadband antenna incapable of sending signals beyond a certain range. Compounded with the low polling rate of the ground idle state that RotaSat was flown in, only a small percentage of the expected data was received. Despite the malfunctions, the primary mission was completed as a whole, having sent and received data that was eleven times more comprehensive than the original mission stated, with 22 data points coming down with each packet, rather than 2.

As for the secondary mission, the video streaming and reaction wheel platforms were not activated due to the state error, providing no data for this flight. However, the main purpose of RotaSat, serving as a template for future satellites, was accomplished. The CanSat was recovered with no issues at all, and the entire modular airframe stayed fully intact and operational throughout the flight and landing. RotaSat would have been capable of another flight within a few minutes of recovery, if that was the intention.

In short, this particular flight for Team Zephyr was not a complete success, nor was it an outright failure. It proves the main objectives of the satellite are viable, yet was unable to complete anything else. RotaSat, as a CanSat, will need much more testing to verify its capabilities and increase its reliability. However, RotaSat, as a template for future satellite constructors, is ready for use.

VII OUTREACH PROGRAMME

The team has made efforts to expand outreach to a variety of platforms: operating several social media accounts, hosting an official team website, giving in-person educational presentations and gaining coverage on local news organisations.

VII.I Social Media

Our social media presence consists of: an Instagram account (Fig. XXIV), a Twitter account (Fig. XXV) as well as a YouTube channel (Fig. XXVI). Instagram and Twitter are where the team publicly showcases project updates, promotes sponsors and shares team experiences. Through the team account's followings, post features and takeover videos, we have reached over 110,000 people on Instagram alone. The RotaSat project trailer video on YouTube has over 900 views.

Fig. XXIV: Team Zephyr's Instagram Account

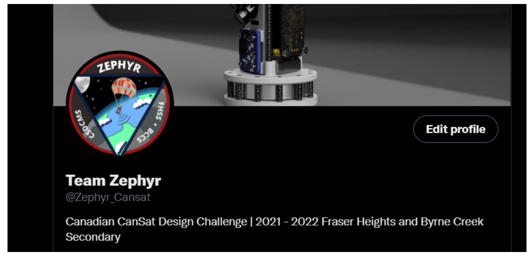

Fig. XXV: Team Zephyr's Twitter Account (@Zephyr_CanSat)

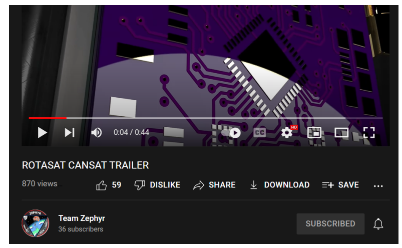

Fig. XXVI: Team Zephyr's YouTube Trailer and Channel

VII.I.I Women in STEM Outreach

Jessica and Vhea have also promoted to many "Women in STEM" communities by hosting Instagram takeovers and through post features (Fig. XXVII). Takeovers lasted an entire day, and the host posts videos and answers questions from viewers. The girls have used their takeovers to explain and answer inquiries about RotaSat, objectives and accomplishments while raising awareness about the CanSat competition and encouraging other passionate young women to explore engineering fields.

Fig. XXVII: Team Zephyr Feature (@engineering_gals)

VII.II Website

The website (Fig. XXVIII) is the central hub of the team's outreach. It contains a display of our social media, technical information on RotaSat, short descriptions of each team member and a photo gallery to display the progress made during development. It also features an animated render on the home page displaying the construction process of the RotaSat, as well as an assembled and disassembled animation showcasing the structure of the CanSat, accessed through scrolling.

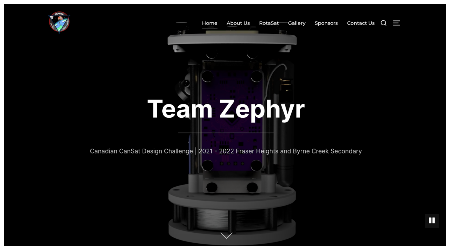

Fig. XXVIII: Team Zephyr's Official Website Homepage

<u>VII.III Educational Outreach</u>

Multiple presentations were hosted to diverse audiences: Mountainview Montessori elementary school students (Fig. XXIX), high school students from Fraser Heights Secondary (Fig.XXX) and Byrne Creek Community, the Fraser Heights parent community, and teachers at Fraser Heights Secondary (Fig. XXXI). In addition to presenting details of the CanSat and competition, interactive activities such as a "Kahoot" quiz and virtual satellite and rocket development exercises were included to engage audience members.

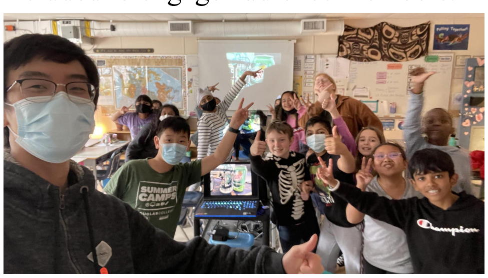

Fig. XXIX: Presentation at Mountainview Montessori Elementary

Fig. XXX: Presentation to Fraser Heights Science Club

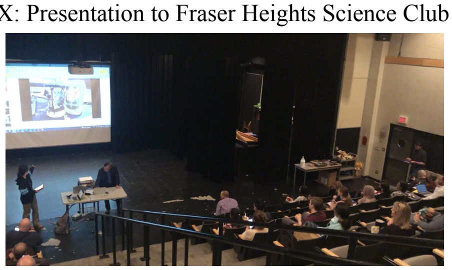

Fig. XXXI: Presentation to staff of Fraser Heights Secondary School

<u>VII.IV News Coverage</u>

Following the national competition, Team Zephyr has been covered in multiple news articles, including SpaceQ (Fig. XXXII), Surrey School News (Fig. XXXIII), the Burnaby Beacon (Fig. XXXIV) and the Canadian Space Agency's Twitter page (Fig. XXXV).

Fig. XXXII: SpaceQ Article about Team Zephyr

Fig. XXXIII: Surrey School News Article

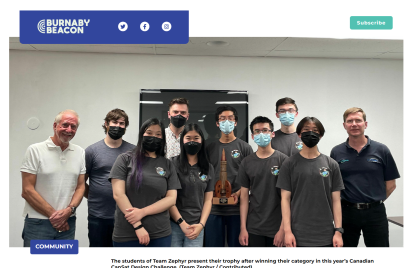

Fig. XXXIV: Burnaby Beacon Article

Fig. XXXV: Canadian Space Agency Twitter post (@csa_asc)

VIII CONCLUSION

Team Zephyr faced many hardships during Canada's national competition, from telemetry signal issues to being unable to recover RotaSat. However, this experience allowed the team to reflect upon and improve the project. The adjustments made to the recovery system proved to be beneficial in the international competition, as RotaSat's GPS location was accurate to within one metre during the launch and was located shortly after landing.

The greatest setback of the European Space Agency launch was being unable to send an integral manual command, which made it impossible for the satellite to advance state. Being stuck in the "Ground Idle" state for the entirety of the flight resulted in cascading failures, including the inactivation of RotaSat's reaction control wheel, live video streaming, as well as a large portion of the data.

Though disappointing, the team soon realised that many unforeseen problems and human error could have been prevented through more robust testing. As technical development had been the main priority during RotaSat's development, the team did not place enough focus on testing the satellite's various components, and time was managed inefficiently. These are lessons well learned for the future, not just for Team Zephyr, but for all who come after.

Through this competition, Team Zephyr has realised the importance of consistent and well designed testing procedures for engineering projects, and have taken yet another step forward in developing the future of standardised CanSat systems.

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