Trident CanSat

CanSat Trident Pre-Launch Report for the European International CanSat Competition by the European Space Agency

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Summary

This report details Team Trident, its CanSat design, design choices, economy, budget, and advertising. This document provides insight on how the team is operating, what has been done, how, why and by whom.

Abstract

Designing a satellite is no easy feat. It requires dedication and a lot of work. Trident concluded using a three-armed drone with the capabilities of guided landing that samples the air for a variety of gasses shortly after the process started.

Proceeding with the tri-copter idea, the team started development. The decision was quickly made to use a Raspberry Pi Compute Module 4 for its fast computing capabilities, and a PID controller was to be implemented in the software. This enabled stabilization of the CanSat, and guided navigation. To be able to control all axes of rotation, one of the arms was designed to be able to rotate to vector the force of its propeller.

To promote the project and gather funds, a website was created, and shortly after, the merchandise was available to be bought there. The website's objective was to inform interested people of the concept and to provide information and marketing space for potential sponsors. Seven sponsor deals were done and the funding was secured. The funding was primarily used to develop prototypes to check what works and what didn't.

1 Mechanical Design

1.1 Concept

To challenge the competition, a unique and creative way to design the CanSat and complete the assignment set was devised. The idea that was decided upon was a powered landing from a drone. Due to restrictions with the small form factor, the decision to use three foldable arms was made. This is how the CanSat ended up with its three signature rotor arms, which lead to the name 'Trident'.

The arms are spring-loaded and will be realized after deployment while in the air. They are connected to the body of the CanSat through bearings that are threaded over a metal rod. Following the deployment, the rotors will keep the CanSat within a vertical velocity of 5 to 12m/s. The flight will end in a soft landing provided by the increased thrust of the propellers. Due to limited space, a creative way of making both the rotor arms and rotor propellers was needed, However, with the sacrifice of the fourth rotor arm comes inherent stability issues.

Three arms meant it was no longer possible to control the yaw. To address this issue, a solution where the third arm could vector its thrust was put in place.

The design procedure was of iterative design, namely setting all the restrictions of building it and making changes to the design features which did not meet the design restrictions.

1.2 Materials

All the mechanical parts are either metal or 3D-printed in resin. The resin allows rapid prototyping as well as a strong frame for the electrical components to connect to.

1.3 Troubleshooting

The problems with the mechanical designs were mostly due to the fact that this was completely new to the design team. The first problem the team had, and solved, was the constraint of space between the pcb, batteries and the components for the moving arm. The problems were solved by trying to print parts with a given tolerance, then reducing the tolerance until it was too tight.

There were also expansive issues concerning the spring release system of the arms. This was solved by the use of physical prototypes and exploring different ideas to find out what worked best. Some of the bigger changes to the CanSat through the troubleshooting were arm length, arm strength, arm cable path, body structure and the internal spacing between the batteries and the arms.

2 Electrical Design

2.1 Microcontroller

To allow for actively stabilized flight, one is dependent on a plethora of components. The CanSat will have to be aware of its current position, rotation, and altitude. it will also track how all of those values change over time. As a result, one needs a lot of computing power, a simple Arduino won’t be able to keep up with all the computing necessary. This brought the team to use a raspberry pi compute module 4 (RPiCM4).

RPiCM4: This microcontroller allows for many computations to be done, while still keeping a small enough form factor to fit in a CanSat. The RPiCM4 offers plenty of General Purpose Input and Output (GPIO) ports to be used for sensors and outputs. The drawback of using an RPiCM4 instead of a smaller less capable microcontroller is its power consumption. Therefore the team decided to add an additional microcontroller to turn on or off the RPiCM4, for this an ATTINY85 was chosen.

ATTINY85: The ATTINY85 is a tiny microcontroller that consumes very little power while still being able to perform the necessary operations. This microcontroller was chosen due to its small physical size, small power draw, and ease of programming. The task of the ATTINY85 will be to act as a middleman between the team and the RPiCM4. It is connected to the RPiCM4 and the communications module using two separate UART busses, in addition to being connected to the power up and down pin and the RPiCM4. Commands will be sent to the ATTINY85 telling it to power up or down the RPiCM4, as well as commands telling it to pass through data from the RPiCM4 to send back to the ground station.

2.2 Components

RFM96: The choice of antenna module came down to what module has the best reliability, ease of use, power consumption, and working distance. The RFM96 passed all of the requirements and seemed a better option than the alternatives.

MPU6500 Gyro/Acc: Compact and versatile sensor which is easy to communicate. Allows for configuration of sensitivity and resolution. I2C.

L80-M39 GPS: Good GPS module, simple to communicate with, SPI.

GM-402B Methane and Propane: Simple to communicate with, also well-documented. I2C.

SGP30-2.5K Ethanol and H2 : Changes resistance depending on how much gas it detects. It is somewhat complicated to measure with it, but well-documented and compact.

MCP3008-I/SL ADC: Used to process analog data, such as measurements of ethanol and H2.

PCF85063AT/AAZ RTC: Recommended by the RPI team.

DS18B20U Temp sensor: Good experience using this sensor, easy to communicate with. Requires only a few GPIO pins.

MS563730BA03-50 Barometer: Compact, simple communication. I2C.

TH02 SI7005 Humidity: Compact and easy to communicate with. I2C.

All these electronics need to be controlled via Pulse Width Modulation (PWM), therefore a PWM controller was needed. PCA9685PW, 118 PWM Controller was chosen. This is necessary because the RPiCM4 only has two PWM outputs, additionally, the controller is easy to communicate with, using I2C. The controller possesses data at a high speed and produces accurate PWM signals.

2.3 Troubleshooting

The first time the CanSat was powered on, activity in the form of blinking leds was observed for thirty seconds and then the leds turned off. A few minutes later they turned back on, before turning off again. It was deemed that the cause of this boot loop was the 3v3 line originating at the Raspberry Pi's internal 3v3 voltage regulator. The leading theory is that the line, which supports 600 mA of current, was overloaded. The RPi went into a protected state. After this, the RPi would cut the 3v3 line, which sent power to the Arduino. By turning off the arduino the RPi would reset. This caused a boot loop. The issue was fixed by adding an external 3v3 regulator capable of delivering 2000 mA of current.

The second version of the PCB did not boot at all. The cause of this was the SD card protection circuit. The integrated circuit chosen could either allow reading the SD card's contents, or allow writing to it, but it could not do both. For this reason, the RPi was unable to boot. This issue was solved by using a RPi with internal EMMC memory. By doing this, the IC would not be in use.

Lastly, none of the RFM9x radios were wired correctly. Therefore, another radio, HC12, was used for the Arduino because it could be wired on the pads as the RFM9x and therefore not require a new PCB. For the RPi, it was decided that the data communication would go entirely over WiFi.

3 Software

3.1 Language

It is common to program the Raspberry Pi family of microcontrollers in Python. When optimizing speed is required, programmers usually choose to write code in C or C++. Trident ended up choosing Python for programming due to ease of use and the ability to write multithreaded and multiple processes at once. It is believed that by writing a slower program, Python, with multithreading, rather than a faster program, c++, without multithreading, the program will run faster.

3.2 Body to World Conversion

The sensors on Trident do not directly measure the rotation and attitude of the craft. Instead, they measure the gravitational force on each axis, as well as rotational speed and magnetic field strength on the same axes. To convert from the read data to real-world heading and attitude, an Extended Kalman Filter (EKF) will be used. This filter takes into account all the measured data and converts it into three outputs, pitch, yaw, and roll. Instead of writing this from scratch, python's Attitude and Heading Reference System (AHRS) library will be used.

3.3 PID Control

The standard way of controlling drones, and the one trident uses, is using a Proportional-Integral-Derivative (PID) controller. The basic working principle of a PID controller is the summation of three control signals, a difference (P), derivative (D), and integral (I) of the device's position. It produces an output steering signal that is capable of knowing what reaction the device has on the steering, and applying that as gain or dampening of the steering.

$$u(t) = K_{\rho}e(t) + K_{i}\int_{0}^{t} e(\tau)d\tau + K_{d}\frac{de(t)}{dt}$$

The K values are the weights of the P, I, and D, and each term is summed to produce an output. Each weight will need to be tuned to produce the desired output, where the drone is reactive but does not over-correct.
One PID controller is required per axis of steering. Pitch, yaw, roll, altitude, latitude, and longitude will therefore require their own PID controllers. These controllers will feed their outputs to three motors and a servo using the following formulas:

$$Motor\,1 = thrust + pitch + roll/2$$
$$Motor\,2 = thrust - pitch/2 + roll/2$$
$$Motor\,3 = thrust - pitch/2 - roll$$
$$Servo = yaw$$

3.4 Data Encoding

Sending and storing the data collected directly would make it challenging to process the data post-flight. Therefore it will use a standardized format for both communication and data storage. The formats used are described in Tables 3.1. Data will be stored both at the receiver and in the CanSat as comma-separated, CSV, files. The data sent over WiFi will be a shortened version of all the data being logged locally. To allow for the most post-flight analysis, all data collected, including all signals sent to the motors, will be stored.

3.5 Communication Protocols

Due to the radio problems described earlier, the WiFi connection between the CanSat and the ground station had to be used for data transfer, as well as video streaming. The protocol that will be used for this is the Berkeley Software Distribution (BSD) socket interface. This protocol opens a connection between a server and a client. In this case, the ground station is the server and the CanSat a client.
The ground station will use the programming language Processing, a java-based language developed specifically for the use of graphical applications. When the program runs, a server is started on port 5000. When the CanSat program runs, it will periodically try to connect to the server. If it is unable to connect, it will wait a second before trying again. If it can connect, it will start sending data as comma-separated values.

The video will not be sent over a socket, but as a subprocess using vlc for streaming the video as an IP camera. In this case, the CanSat acts as a server, streaming the information that video is available continuously, and when the client (ground station) connects, it will start streaming video. This saves processing power when no client is connected.
In addition to sending video, the CanSat takes images as often as possible. This is around 2 images per second, per camera. When the images are being captured, the video is paused without disconnecting the client. This allows for simultaneous video and image taking on the same camera.

3.5 Sensor Interface

The majority of trident's sensors use the Inter-Integrated Circuit (I2C) interface, a two-wire protocol for serial communication. This, in addition to extensive library support, makes the software interface with them easier. The majority of interfaces that do not use I2C use the Universal Asynchronous Receiver/Transmitter (UART) protocol. The advantage of UART over I2C is the configurable interface speed, which allows for dynamic CPU usage and dynamic throughput.

4 Public Relations

4.1 Website

A website was created to advertise the project to people interested, as well as to bring something concrete to sponsors to convince them to sponsor Trident. The website started simple with a homepage but grew very quickly as new ideas came to mind. The website can now be found at https://cansat-trident.space/.

On the website, you can find everything, from info on the members of the team to sponsors and merchandise. The website also brings the latest information on mechanical design and 3D models of current versions.

4.2 Logo Design

The Logo depicts a soda can with propellers being launched to the edge of space, the soda can is the Trident and the three propellers are the reason it is named Trident.
On the earth you can see Andøya and around the earth there are colored stripes meant to represent the Norwegian flag.

5 Economy & Budget

Trident’s design is costly, from the sensors to the control components. Trident has had two main sources of income; sales and sponsors. This, combined with contributors, has raised the team €2000, which is for the budget of the CanSat, ground station, and the purchase of merchandise.

5.1 Budget

Most of the budget went into acquiring merchandise and ground station equipment - which does not count towards the budget of the CanSat - as well as reserved non-flying items.
A list below details the CanSat budget:

5.2 Sponsors

From an early stage, sponsorships were set on the agenda, realizing that sponsors were necessary to secure funds for prototyping and development of the CanSat. A standardized email was created and together with personalization for each company that was contacted, many emails were sent.

5.2.1 Andøy Bok- & Papirhandel AS

The first sponsor of CanSat Trident came through the family of one member. This made early development and part-gathering possible. The Sponsorship consisted of €100.

5.2.2 Joker Bleik

Joker Bleik was Trident's second sponsor. The sponsorship from them made the purchases of electronics possible. The sponsorship consisted of €493.

5.2.3 Polyalkemi

Polyalkemi was the third sponsor of CanSat Trident. The sponsorship made it possible to gather stronger resin for the 3D-printed parts. This allowed for thinner walls and a body with smaller mass. The sponsorship consisted of resins.

5.2.4 Andøy Energi

Andøy Energi was the fourth sponsor of the team. The Sponsorship consisted of €493.

5.2.5 HobbyKing

Hobbyking was the fifth sponsor of CanSat Trident. They helped the team to stay safe and monitor batteries with 4 battery monitors. This kept them properly balanced and charged.

5.2.6 Elefun

Elefun was the sixth sponsor of Trident. The Sponsorship consisted of batteries and extra motors.

5.2.7 4test

4test was the seventh sponsor of the team. The sponsorship consisted of an oscilloscope on loan, which was used for troubleshooting components and circuits.

5.3 Sales

Both as a source of income and advertisement, the decision was made to start selling T-shirts with Trident's logo on them. After sourcing T-shirts for cheap, the team realized T-shirts could be sold for less money to people who may not have enough money to buy an expensive T-shirt to support the team. Therefore a dynamic pricing system was put in place where you would have to pay a minimum of €15 for the T-shirts, with the option of paying more.

Andøy Bok- & Papirhandel let the team sell T-shirts at their store at the same price as normal. This allowed the T-shirts to be sold passively and without having to be delivered by the team, saving time and money to focus on other tasks. Additionally, this helped the team gain exposure among customers who otherwise might not have heard of Trident, reaching more people than before.

6 The Trident Team

6.1 Overview

The Trident team consists of six members from different parts of the country. The team members include Team Leader Gabriel Røer (19), Team Manager Mats Haugerud (20), Economy Manager Lukas André Bendiksen (19), PR Chief Maximilian Christoffer Olsen (18), Graphic Designer Wiktor Mikołaj Becker (18), Secretary Felix Andreassen Jørgensen (19), additionally, Hallgeir Solstad Klæboe (27), is the teams' Guardian Teacher for this project.

6.2 Meetings & Organization

Meetings are held to organize the team's efforts, and responsibilities and also act as a way to receive in-person updates on the status of work relating to the project. The meetings are not held on any specified, regular schedule, but are instead prepared, announced, and held as needed. This is usually when there is a major design decision to be made, updates are needed, or at the request of the Team Leader.

Meetings are announced on the application Discord, usually, a Microsoft Word .docx file is uploaded onto Discord which details when and where the meeting is to take place. Additionally, information about the different subjects to be discussed, or decisions to be made will be listed in the document. Sometimes, all of this information is written just as plain text, this is done to inform the team as quickly as possible and this only happens when there is an urgent need to hold a meeting, usually due to uncertainty in design, or to propose a new solution or suggest changes to one.

After a meeting, another document that details what was discussed and which decisions were made gets approved by all of the members present in the meeting. This document is then subsequently uploaded to the teams' group on Discord in a separate category exclusively reserved for such files. This is done to organize the team, and also acts as a way for members who were sick, or could otherwise not attend the meeting to still get updated information about the decisions made, or what to do as decided during the meeting.

Due to the members of the group attending the same school, there are usually some extra discussions and conversations on topics related to, or directly concerning the project held during breaks. These talks do not usually result in major overhauls or decisions being made, and therefore meetings are not required in their place. This has the benefit of freeing up additional time which can be spent working on the different areas of the project. The team has a largely decentralized structure, so outside of the meetings, members work on what they want to do when they want to. This makes sure that members are always motivated to do what they are doing, and prevents burnout.

6.3 Members

6.3.1 Team Leader: Gabriel Røer (19)

Responsibilities: Physics Theory, General Design, Organization, Secondary and Primary Mission, CAD/CAM.

School: Andøy Upper Secondary School – Space technology.
E-mail: NorgeSkiFollo@gmail.com
Phone: +47 469 10 340

Biography: For as long as I can remember, I have always had an interest in finding out how things work. Picking things up and pulling them apart and putting them back together just to see what they are made of and how they work. That is why electronics and technology quickly became a natural topic of interest, just like space technology later in life. That is also why my first reaction when I heard about this competition was “this is something I need to participate in”, and why I started this CanSat team.

Contribution to the team: As the team leader, my job is to guide the team towards a common goal. I have also had a hand in both the mathematical design, and the math behind the electronics.

6.3.2 Team Manager: Mats Haugerud (20)

Responsibilities: Mechanical Design, Website Design, CAD/CAM, Software design.

School: Andøy Upper Secondary School – Space Technology.
E-mail: haugerudmats@gmail.com
Phone: +47 950 40 971

Biography: Since the first time I picked up an Arduino, I have been amazed. The endless possibilities it creates have been something I have sought to explore for the past three years. To be able to continue my journey as a part of a team is something I could not say no to. Sharing experiences and thoughts on problem-solving is something I look at as a good opportunity to develop my skills further and learn new things.

Contribution to the team: My job at Trident is to do the mechanical design, make the website, help with electronics and write the software for the CanSat and ground station.

6.3.3 Accountant and Designer: Lukas André Bendiksen (19)

Responsibilities: Hardware, Mechanical, and Electrical Design, CAD/CAM, Economy, Account management, Secondary and Primary Mission.

School: Andøy Upper Secondary School – Electronics and Computer Technology
E-mail: Lukas.bendiksen@gmail.com
Phone: +47 905 32 258

Biography: I am greatly interested in everything considered STEM. I actively do stuff within electrical and mechanical engineering and a little programming. I joined the project since it sounded like a challenge. I wanted to solve problems, and contribute to the project succeeding.

Contribution to the team: I have taken a look at budget, managing the accounts and helping with mechanical design, electrical and hardware. I also assist in other fields.

6.3.4 Secretary: Felix Andreassen Jørgensen (19)

Responsibilities: Documentation, Writing, Editing, Organization.

School: Andøy Upper Secondary School – Space Technology.
E-mail: felixandreassenpost@gmail.com
Phone: +47 942 61 638

Biography: I have always been interested in both space and technology, especially how the two interact with one another. Even though I am not particularly involved with the actual design of the CanSat itself, my interest in both fields were my primary reasons for joining the team. Additionally, I thought the competition seemed interesting, and I wanted to take part in a bigger group project and hopefully gain valuable experience from participating in it.

Contribution to the team: Primarily, I have been assisting with writing and the organization of the team's meetings, as well as pitching the use of cameras.

6.3.5 PR Chief: Maximilian Christoffer Olsen (18)

Responsibilities: Graphic Design.

School: Andøy Upper Secondary School – Space Technology.
E-mail: maximilian.christoffer.olsen@gmail.com
Phone: +47 458 44 217

Biography: not much to say, I enjoy being a part of this team and I design logos plus whatever else is requested of me. I haven't been given the most remarkable tasks of this project but I am fine with that, it's been a fun adventure regardless.

Contribution to the team: I made the logo for the Trident CanSat.

6.3.6 Graphic Designer: Wiktor Mikołaj Becker (18)

Responsibilities: Graphics and PR.

School: Andøy Upper Secondary School – Space technology.
E-mail: beckerwiktor@gmail.com
Phone: +47 968 01 127

Biography: Me? I've been interested in space roughly since I was 13, and always dreamt of differing myself from standard society. I'm mostly a gamer, but I'm a positive guy with lots of ideas, and I like making decisions on the spot. Therefore instantly after being announced, I knew I wanted to join the team. I also like working with people, and helping them when they're in need, but the real reason I joined the team was actually because of the people and community. There are a bunch of clever students here in Andøya, so when they announced the project I was sure I wanted to get a good look at it, and to hopefully learn a thing or two along the way.

Contribution to the team: I've come with suggestions, graphic design and design suggestions, translations, correct wording, spelling and positivity.

6.3.7 Guardian Teacher: Hallgeir Solstad Klæboe (27)

Responsibilities: Official communications and guidance.

School: Andøy Upper Secondary School – Teacher
Email: halkle13@vgs.nfk.no
Phone: +47 482 65 911

Biography: For as long as I can remember I have been interested in the universe, especially the planets in the solar system. This interest led me to study science in high school and, some years later, take a bachelor's degree in Satellite Technology at UiT. After I finished my degree, I was lucky enough to get a job within this field as a teacher of Space Technology at Andøy High School. I decided to join the team as the guardian teacher because I had never heard of this competition before and thought it sounded fascinating, and I was severely impressed by the team's plan and was interested in seeing how they would fare in a competition such as this.

Contribution to the team: Communication between the team and Andøya Space, as well as giving the team hints and tips when asked.

6.3.8 Guardian Teacher: Stein Ove Hagen (47)

Responsibilities: Guidance and Safety.

School: Andøy Upper Secondary School – Teacher
Email: stehag@vgs.nfk.no
Phone: +47 913 72 416

Biography:

I have always been interested in electronics and programming so after going to vocational college to become an electrician, I went to college to get a bachelor's degree in electronics. After working for some time at Alcatel Distribusjon I started teaching at Andøy upper secondary school where I work now.
I joined the team both because the team needed a second mentor because of Covid-19 regulations, and because I find the CanSat competition very interesting and educational for my students. Everything falls right into the curriculum for the subjects I teach.

Contribution to the team:

I hope I can contribute with tips and help when asked and other needed support.

7 Conclusion

Through hard work and dedication, the team has been able to develop a concept and make the CanSat real. Facing challenges, the team has been dynamic and has been able to overcome what is needed to be able to create and fly a CanSat tricopter.

Professional documentation and working methods have ensured that everyone in the team is updated and knows what they need to do after a meeting. In addition, it has allowed the team to communicate easier.

Appendix

Tables

Table 3.1: Communication format

Frame	0	1	2	3	4	5	6	7
Data	Time [ns]	Latitude	Longitude	Altitude	Satellites	Velocity	Pitch	Yaw
Format	16d	02.6f	02.6f	05.4f	02d	03.4f	1.8f	1.8f

8	9	10	11	12	13	14	15	16	17
Roll	Temp	Humidity	Pressure	Goal Lat	Goal Long	Goal Alt	Goal Pitch	Goal Yaw	Goal Roll
1.8f	03.5f	03.4f	03.4f	02.6f	02.6f	05.4f	1.8f	1.8f	1.8f