Pre-Launch Report

Team NovaDomus

Norway

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Introduction

We are a CanSat team consisting of six students from Thora Storm upper Secondary School in Trondheim, Norway. All of us are second year students of the educational program Sciencelinja, which has a focus on science and mathematical subjects. Our interests range from programming websites, solving the rubik's cube, video games, cramming the periodic table, physics, creating cosplay, ballet, rock climbing, football and memorizing pi. With the guidance of our beloved project manager Adrian we are all dedicated to conquer any storms headed our way.

Team compositions and roles

Role	Name
Team Captain	Tiril Svaasand Eliassen
Spacecraft Communicator (CAPCOM)	Aasmund Gabestad Nørsett
Aerospace Engineer	Emilie Strømnes Meland
Failure Prevention Scientist (F.P.S)	Sebastian Westerlund Kalland
Physicist	Thyra Rolfseng
Software Engineer	Tobias De la Plaza Domaas
Project Manager (teacher)	Adrian Heyerdahl

Mission objectives

Primary mission

As part of the Nordic CanSat competition each team is required to have a primary mission. This primary mission is to measure atmospheric pressure and temperature. These values can be used to calculate the CanSat's altitude at any given point. The relation between temperature, air pressure and altitude is given by the following formula $h = \frac{T_1}{\alpha}\left(\left(\frac{p}{p_1}\right)^{-\frac{\alpha R}{g_0}} - 1\right)$. The formula contains 3 variables and 3 constants. T_1 and p_1 are temperature and air pressure at starting position. These variables can be measured before the launch. α is a constant of how temperature changes based on altitude in the troposphere, R is the gas constant for dry air and g_0 is the gravitational acceleration. Therefore, if the CanSat measures the current air pressure during the whole descent, we can calculate the altitude of the CanSat. The altitude will be useful when analyzing the values from our secondary mission, as it will inform us at which point during the descent the measurements were made.

Secondary missions

What makes a planet sustainable for human life?

In order for a planet to sustain life certain requirements must be fulfilled. Our CanSat is made with the purpose of measuring data relevant to these requirements. The measurements will allow us to determine whether the climate of a planet is habitable. Space inside a CanSat is limited, and therefore we have had to prioritize. We have deemed these factors to be the most important: temperature, atmospheric pressure, humidity, atmospheric structure, level of harmful electromagnetic radiation, and the strength of the planet's magnetic field.

Magnetic field

Stars provide warmth and energy to the surrounding planets. They can, however, also be dangerous. Charged particles are sent out in all directions, known as solar winds. These particles are dangerous and they pose a significant danger to life on surrounding planets. In order to protect against solar winds Earth is equipped with a magnetic field that redirects most charged particles. Because of this, our CanSat will measure the magnetic field of the planet.

Atmospheric structure

All life forms we know of, from single celled to complex, multi celled organisms, require a specific range of substances to survive. The most important of these are *oxygen* (O_2) and *water* (H_2O). Our CanSat will measure both oxygen level and air humidity. Air humidity is a good indicator of whether there exists water or not on the planet.

Ultraviolet Rays

In addition to solar winds, stars emit a wide range of dangerous, ionizing radiation. If this radiation was to penetrate the atmosphere and reach the life forms on the planet it would rip apart the atoms building up the cells. It is therefore crucial that the atmosphere has a way of protecting against such radiation. The earth has ozone, but any way of stopping the radiation would work, and we will therefore measure the UV-radiation level in the atmosphere.

CanSat description

Mechanical and structural design

For the mechanical design of our CanSat, we have made the most out of the available space the can may offer. The structure is built in a way that prevents the components from breaking upon impact. Our CanSat is built of a 3D-printed shell and an aluminium bracket for the electronics. When planning the mechanical design we have taken into account the antenna's position, the sturdiness of the CanSat, and making the interior components easily removable.

The aluminum bracket

There exist several designs of the aluminium brackets for CanSats. We have chosen to use Narom's suggestion due to how well it can fit the Arduino Uno (and other) boards (figure 1). The attached drawing shows the dimensions and the placements of the holes. Though because we would like to use a more powerful board we have made some adjustments in order to fit an Arduino Mega. We have produced brackets at NTNU with different heights: 92, 108 and 110 mm (figure 2). The aluminium plate is bent inwards on top and outwards on the bottom. We have additionally added holes for the strips made to fasten the battery.

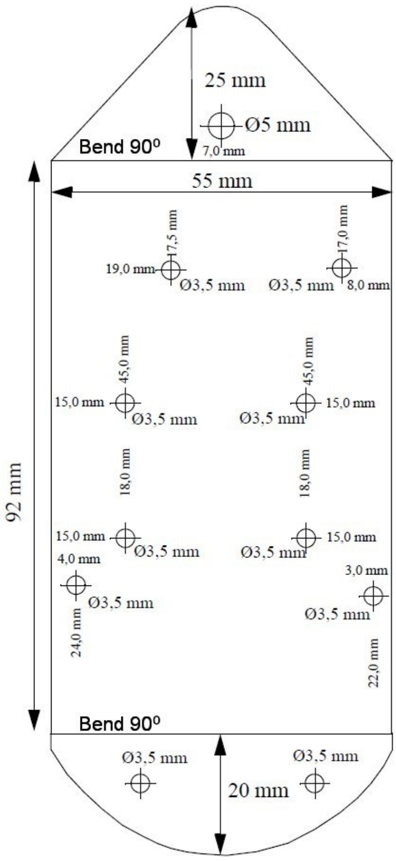

Figure 1 Narom's alunium bracket design.

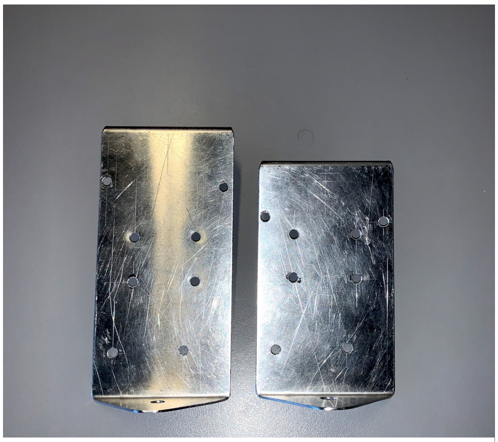

Figure 2 Two of the three brackets produced by NTNU.

Antenna design

The antenna that is included with the APC220 radio is a 433 MHz Rubber Duck antenna. This antenna won't fit in our CanSat and we have therefore used an alternative thread antenna that has been connected to a SMA-connector (figure 3). The antenna length can be calculated from the equation $L = \frac{c}{4 \cdot f} = \frac{3 \cdot 10^8 m/s}{4 \cdot 434 \cdot 10^6 Hz} = 0.173\ m$. We made the antenna by using a coaxial cable where we removed 17.3 cm of the plastic coverage which leaves the dielectric insulator and the centre core.

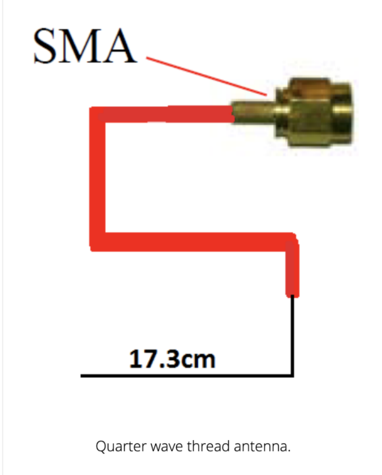

Figure 3 Illustration of the antenna with the SMA-connector.

3D-printed shell

Our CanSat's outer shell is a team-designed, 3d-printed can (figure 4). It was designed in Sketchup and printed at the Trondheim Science Center. The material used is PLA with carbon fiber, an easy print yet extremely tough material, and the shell's design includes holes to make a ventilation system. This causes a cooling of the electrical board which makes the temperature inside more stable. In addition, it makes the temperature sensors give more accurate results.

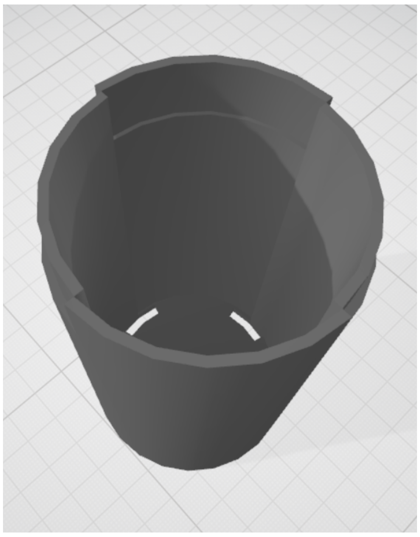

Figure 4 View of the .obj file from windows 3D viewer.

Electrical design

Our CanSat is based on an Arduino Mega and a PCB shield designed with assistance from our project manager. The PCB (printed circuit board) is the circuit board that electrically connects and mechanically supports the electrical components of our CanSat. The connections are made with a series of conductive tracks from copper sheets laminated onto a non-conductive material (Digi-Key, 2018).

We designed our PCB in a computer-aided design software called Multisim. At first we designed a circuit. This was based on a prototype which was constructed on a breadboard with current carrying wires (figure 5). The prototype allowed us to design, experiment and test the circuit connections before we made it permanent. The breadboard was a favourable prototype because it didn't require soldering. On the other hand, the prototype wasn't suited for the CanSat due to all the wires. The PCB is a permanent board where the interconnections between the components are made through copper tracks instead of wires. A printed circuit board exterminates the possibility of the wires unplugging during the launch and is a more structured way of designing an electronic system.

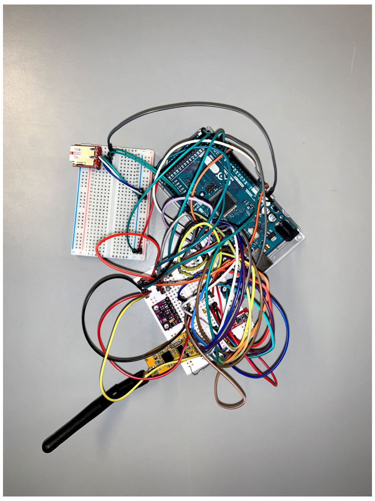

Figure 5 The prototype of our advanced CanSat.

We drew the schematics in the software schematic capture program (figure 6). The schematics convey the electrical connection between the different active and passive components. The elements and sensors are represented by graphic symbols. The components are represented by rectangles, with pins extending out of the sides. Each pin links the component to a pin on the Arduino Mega. The components therefore vary in size and pincounts.

The Arduino Mega is based on a 5V system. It has 54 digital I/O pins and 16 analog inputs and outputs. We looked at each sensor's data sheet to determine what the footprint, the configuration of pads and holes on the PCB, should be. You can see the footprint in figure 8. Our PCB is a 2 layer board which means that both sides of the board has conductive material on it. The bottom layer of the PCB is 5V while the front layer is GND. The green traces represent the copper connections on the front layer and the red ones represent the bottom layer.

After the footprint was drawn, we designed the board layout. We placed the parts in the program and drew copper connections, traces, between the necessary pins. Finally, we printed a prototype of the PCB at NTNU (figure 7) and ordered the final product from JLCPCB. We could easily solder components to the PCB from NTNU and it worked well as a prototype. However, it didn't have any layer of protection to help prevent short circuits unlike the PCB printed by JLCPCB.

The sensors are soldered to the PCB. The sensors are marked with text (silk screen) both on the PCB and on the footprint (figure 8). The humidity sensor is on the top right. On the bottom right the UV-sensor and the GY-91 board can be seen, and the Grove O_2 sensor is located at the center of the board. The MLX90614 temperature sensor is placed on the top right side, and the NTC temperature sensor can be found between the MLX90614 and the Grove O_2. The openlog and the antenna are under the temperature sensors. All the sensors we have used, except for the temperature sensors, are breakout boards. The concept of a breakout board is that is takes a single electrical component and makes it easy to use (Programming Electronics Academy, n.d.). It "breaks out" the pins that supply power, provides ground, receives input and sends output onto a PCB that has its own pins. Therefore, it's easy to solder the breakout boards to the PCB shield board.

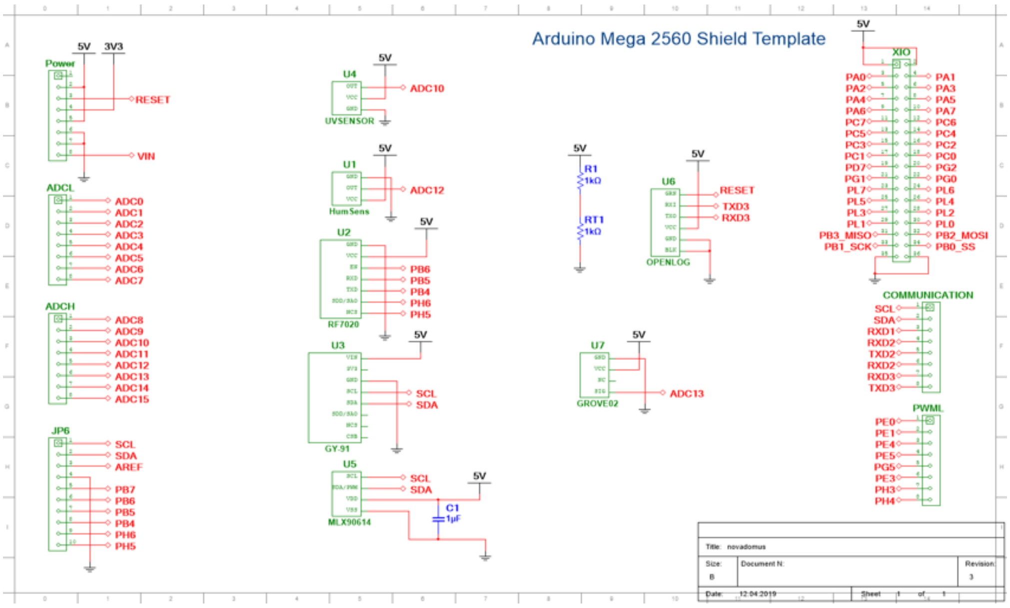

Figure 6 The *schematics* of the PCB.

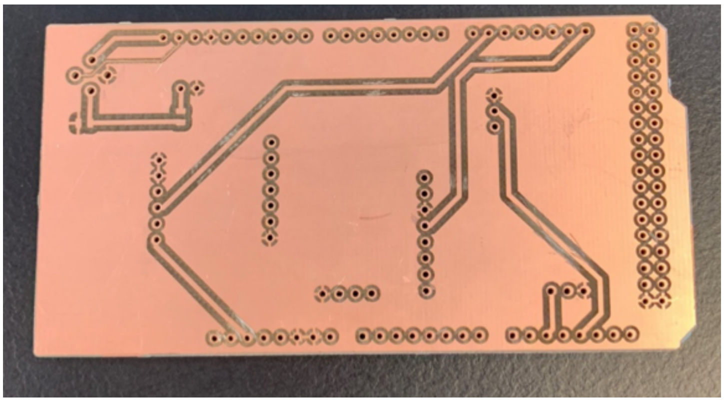

Figure 7 The prototype of the PCB which was produced by NTNU.

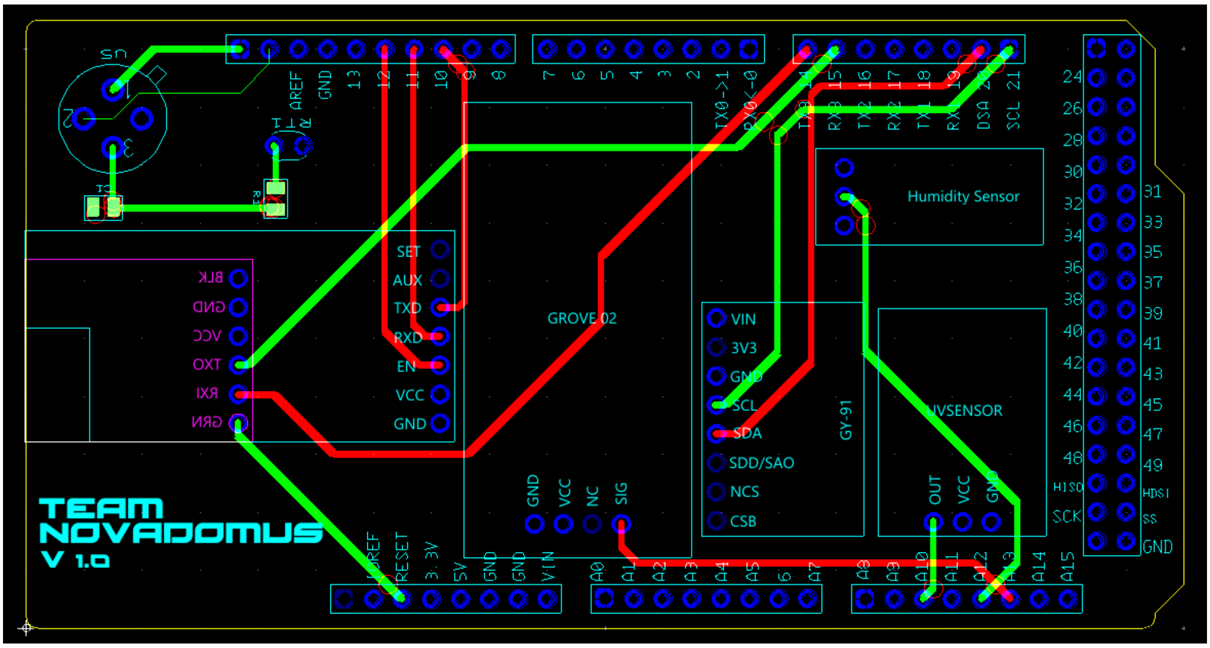

Figure 8 The footprint of the PCB.

Components

1. Arduino Mega

   This is the main component and the "brain" of our CanSat. The Arduino is where the code runs and sensor data is handled, and it connects all other pieces together.

2. APC220

   The APC220 is a radio communicator that allows us to send and receive data from the CanSat. This way, all the data collected by the CanSat can be sent directly to a ground station whilst we control some software options on the CanSat.

3. SparkFun Openlog

   The data is saved on an SD card connected to this component. This serves as a backup should the APC220 fail.

4. NTC Thermistor (B57891M0103K000)

   An NTC Thermistor is made of a semiconductor that changes its resistivity according to the temperature. By measuring the change in voltage caused by the varied resistivity we can calculate the temperature. However, this method is not optimal when dealing with rapid changes in temperature. This is due to the fact that it takes a relatively long time for the NTC to adapt and stabilize at new temperatures, but we will still include it in our CanSat for backup and comparison-based reasons.

5. MLX90614 temperature sensor

   In contrast to the NTC Thermistor, this sensor uses infrared light to measure the temperature. In addition to measuring the ambient temperature it can also measure the object temperature of the CanSat. This will allow us to monitor the environment inside the can and make sure everything is working like it should. The reason we are using it is because of its significantly lower response time to change in temperature.

6. GY-91

   The GY-91 is a combination of the two sensors BMP280 and MPU-9255. The BMP280 is a barometric pressure sensor and it will be used to measure the air pressure as required by the primary mission. The MPU-9255 is a three-axis gyroscope, three-axis accelerometer and a three-axis magnetic field sensor. This will allow us to keep track of the CanSat's movements during the decent and detect unwanted shimmy and or rotation.

7. UV sensor

   This sensor will measure the levels of dangerous ultraviolet radiation entering the CanSat. Comparing the values to earth would allow us to determine whether it is habitable or not.

8. Grove O_2 sensor

   This sensor will measure the oxygen levels in the surrounding air with a process based on electrochemical cells. (Seeed, 2018)

9. HIH-4030

    With this sensor we will detect the levels of relative humidity in the surrounding air.

10. Buzzer (AT-1224-TWT-5V-2-R)

    The buzzer is able to make high pitched noises for retrieval. Unfortunately, we forgot to include the buzzer in the PCB-design, and it will therefore be connected by wires.

11. Varta Ultra Lithium 9V Battery

    This battery has 1150mAh of charge and supplies 9V. With all components operating at maximum power drain it will still last an estimated 5 hours.

Software design

As we are using the Arduino Mega as our microcontroller, it is only natural that the software for our CanSat is written in the Arduino version of C. When writing the code we followed a strict structural ruleset to make the code easy to maintain and understand. All sections of the code include short but descriptive comments about the function of the code. Most of the sensors used in the CanSat required their own libraries. Those were included at the very top of the code, to make sure that their methods won't get called before they are included. Directly under those comes the declaration of the global variables. These are separated into what sensor they belong to, which makes it easier for others to read the code, and they are given easy and descriptive names. For the setup() function in Arduino we decided that the best way to handle it was to create individual setup functions for the sensors, as most of the sensors require some additional setup code to be able to use them. The same standards have been used for the loop() function. We have declared functions for each individual sensor, outside of the loop() scope, that reads the values, converts the raw voltage values into their proper units through different formulas, and then prints the converted values to the SD-card, as well as to the transceiver, in an orderly fashion that allows for easy handling of the data.

Communication between the CanSat and the ground antenna works in a way that the ground station is constantly scanning for data from the CanSat, while it also has the option to send additional commands up to the satellite. At the same time the CanSat is scanning for commands from the ground antenna. By default the CanSat will be transmitting data back to the ground antenna, but this is toggleable with commands from the ground. The CanSat will however constantly be logging the data onto an SD-card with the OpenLog data logger, even if the CanSat is not transmitting data to the ground. This way we can ensure that even if the transceiver signal gets disturbed in any way, we will have all the data logged in the CanSat itself.

The APC220 transceiver comes with its own setup program, which is needed to run before it can be used. The setup program lets us configure all sorts of properties for the APC220 such as: the frequency that data gets transmitted/received; how many bits per second that is being transmitted/received between the transceivers; how many megawatts of power are being outputted by the transceiver; how many bits per second that is being exchanged with the arduino itself; a Byte Parity Check which can help us notice if there is a problem with the signal. It is important that both the APC220 on the ground and on the CanSat share the same configurations, or else they will not be able to communicate.

Recovery system

The key component of our recovery system is the parachute. The purpose is to stop the acceleration of the can after the launch in order to gather data over a longer time period and to prevent a destructive crash. In addition we have added a buzzer to make it easier to find the CanSat after the landing.

Parachute

The CanSat will deploy a parachute after launch as a recovery system. The parachute will slow down the can drastically. By doing this it also maintains proper antenna orientation because the parachute ensures that the CanSat stays in an upright position, which produces a greater chance of receiving telemetry. The mass of the CanSat is within the guidelines of Narom. The descent rate will be dependent on the area of the parachute. The formula for calculating the minimum parachute area needed for a safe descent speed is given as $A_p = \frac{2gm}{\rho\ C_d v^2}$. In this formula g is the acceleration due to gravity, m is the mass of the CanSat and the parachute, ρ is the density of air at sea level ($1225\ g/m^3$), C_d is the coefficient of drag of the parachute (estimated to be 1.5 for a semi spherical parachute) and v is the descent velocity of the CanSat ($8 - 11\ m/s$). We have not received a parachute yet as a result of errors y NTNU, but we have made the calculations. If the mass is 325g, the area of parachute would be $A_p = \frac{2 \cdot 9.81 m/s^2 \cdot 0.325 kg}{0.1225 kg/m^3 \cdot 1.5 \cdot (9\ m/s)^2} = 0.4284\ m^2$.Given the area we can find the diameter we need for our parachute with the formula $d = 2\sqrt{\frac{2\ A_p}{n\ sin(360\circ/n)}}$where n is the number of sides of the parachute. Thus, with 6 sides on the parachute, the diameter would be $d = 2\sqrt{\frac{2 \cdot 0.4284\ m^2}{6 \cdot sin(360\circ/6)}} = 0.406\ m$.Furthermore we can find the height in each triangle of the hexagon with $h = r \cdot cos(\frac{180\circ}{n}) = \frac{0.406\ m}{2} \cdot cos(\frac{180\circ}{6}) = 0.176\ m.$

Buzzer

We have added a buzzer to increase our chances of finding our CanSat after the descent. The buzzer will make loud noises, preferably melodies, in order to help us localize the device.

Ground controll

At ground control we will be collecting the data sent from the CanSat with the help of an antenna. This antenna is then connected to the APC220 on an Arduino Uno. This will be further connected to a computer that will gather and save the collected data. We also have an SD card connected to the CanSat in case we experience interference.

Project planning

Schedule

We have been having weekly sessions to keep up the progress throughout the 4 months we have been working. During these sessions we have been learning new concepts, planning and building the CanSat, solving problems and finding new solutions. We decided to set deadlines distantly in the future in order to have a consistent progression.

Month	Deadlines	Phase	Activity
January	15.01.19 (project proposal)	Lessons	Brainstorming and deciding secondary mission.
		Lessons	Web construction starts. Social media accounts.
February	01.02.19 (feedback on the teams selected to participate)	Lessons	Define elements to buy and construct.
	15.02.19 (short project description)	Design and lessons	Mechanical, Electrical and Software design starts.
March		Design, construction and prototyping	Learning and testing of sensors.
		Construction and testing	Software and Mechanical tests.
April	12.04.19 (Pre Launch Report)	Testing	Writing the report and requirements checks.
	23rd - 26th April (The Nordic Competition)	Launch	

Resource estimation

Component	Amo unt	Estimated Price per unit	Estimated Price
3D-printet exterior	1	400 kr	400 kr
Aluminum bracket	1	300 kr	300 kr
PCB	1	25 kr	25 kr
Arduino Mega 2560	1	350 kr	350 kr
9-volt battery	1	100 kr	100 kr
Breakaway Headers 36 pack	2	20 kr	40 kr
APC220 transceiver pair	1	385 kr	385 kr
Sparkfun OpenLog	1	170 kr	170 kr
NTC	1	10 kr	10 kr
MLX90614 infrared thermometer	1	215 kr	215 kr
GY-91	1	100 kr	100 kr
UV-sensor	1	60 kr	60 kr
Grove O_2 sensor	1	540 kr	540 kr
HIH-4030 humidity sensor	1	205 kr	205 kr
Parachute	1	100 kr	100 kr
Micro SD card 16gb	1	100 kr	100 kr
Total	X	X	3100 kr

Sponsors

External support has been a crucial factor for Team NovaDomus. The team has been sponsored by Thora Storm upper secondary school and NTNU Department of Electronics (IES). Thora Storm covered the transportation costs, and NTNU provided components and team equipment. We got access to laboratories, electronic gear and lecture rooms a result of the cooperation with Thora Storm secondary school and NTNU. This formed the foundation for our advanced and customized CanSat.

Outreach

Website

As part of the project we have developed a website to provide information and updates about the team. This website can be found on novadomus.no. The website includes a blog where the team regularly uploads updates on their progress. The blog runs on a node.js server with a realtime Firebase database. There is also a comment section where users can ask questions and give feedback. The entire website is encrypted under a certificate from Let’s Encrypt. Other features of the website includes a photo gallery, documentation and files from the CanSat project, a dedicated page to our sponsors as well as a page showing off our team members.

Social media

In addition to the website we have a variety of different social medias, on which we have posted regularly.

1. FaceBook: Team NovaDomus
2. Instagram: @teamnovadomus
3. YouTube: Team NovaDomus
4. Discord: Team NovaDomus

Requirements

The CanSat meets the requirements listed by NAROM, so it is able to have a safe launch. We have completed the following table by specifying the exact characteristics of our CanSat.

Characteristics	**Figure (units)**
Height of the CanSat	115 mm
Mass of the CanSat	325 g
Diameter of the CanSat	65 mm
Length of the recovery system	N/A
Flight time scheduled	≈ 44.4 s
Estimated descent rate	9.0 m/s
Radio frequency used	433-434MHz
Power consumption	178.9mA - 221.8mA
Total cost	3100 kr

Sources

- Brohm, J.R. (2004). *The Mathematics of Flat Parachutes.* Retrieved from http://www.sunward1.com/imagespara/The%20Mathematics%20of%20Parachutes%28Rev2%29.pdf
- Digi-Key (2018). *An Into to KiCad - Part 1: How PCBs Are Made | DigiKey.* Retrieved from https://www.youtube.com/watch?v=vaCVh2SAZY4&list=PLEBQazB0HUyR24ckSZ5u05TZHV9khgA1O&index=8
- Kazmeyer, Milton (2018). *Importance of the Earth's Atmosphere.* Retrieved January 31, 2019, from https://sciencing.com/importance-earths-atmosphere-5070.html
- Lunar and Planetary Institue (n.d.). *Factors that Contribute to Making a Planet Habitable*. Retrieved January 31, 2019, from https://www.lpi.usra.edu/education/explore/our_place/hab_ref_table.pdf
- Nakka, Richard (2017). *Parachute Design and Construction.* Retrieved from http://www.nakka-rocketry.net/paracon.html
- Narom (n.d). *Transceiver.* Retrieved from https://www.narom.no/undervisningsressurser/the-cansat-book/the-primary-mission/using-the-radio/transceiver/
- National Geographics (n.d.). *Atmosphere.* Retrieved January 31, 2019, from https://www.nationalgeographic.org/encyclopedia/atmosphere/
- Programming Electronics Academy (n.d.). *What is a breakout board for Arduino?* Retrieved from https://programmingelectronics.com/what-is-a-breakout-board-for-arduino/
- Sanders, Robert (2018). *What magnetic fields can tell us about life on other planets.* Retrieved January 31, 2019 from https://phys.org/news/2018-11-magnetic-fields-life-planets.html
- Seeed (2018). *Grove - Gas Sensor(O_2).* Retrieved from http://wiki.seeedstudio.com/Grove-Gas_Sensor-O2/