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Teilnahme am Schülersatellitenwettbewerb CanSat der ESA (European Space Agency). Das Team namens CFP-16-URSinvestigators bestehend aus 6 Schülerinnen hat einen Satelliten in Form einer Getränkedose (Engl.: Can) konstruiert, gebaut und mit einer Rakete auf ca. 2.400 m Höhe geschossen. Das Ziel war es, Temperatur, Luftdruck und Luftfeuchtigkeit in der Höhe zu messen sowie eine Luftprobe zu entnehmen und zur Erdoberfläche zurückzuführen. Trotz gewisser Probleme mit der Antenne zur Datenübertragung war die Mission insgesamt sehr gelungen und die physikalischen Messungen konnten durchgeführt werden. Die mechanischen Teile, von den Mädchen in SOLIDWORKS konstruiert und größtenteils am schuleigenen 3D-Drucker gedruckt, haben die Belastungen gut ausgehalten.

Dieser 10-seitige englischsprachige Bericht kann als gutes Beispiel für andere Gymnasien dienen, wie sie SOLIDWORKS 3D CAD in Technik-, Informatik-, Physik-, Biologie- und/oder Chemieunterricht und/oder -AGs nutzen können.

CFP-16-URSinvestigators

MANUSCRIPT OF THE PROJECT

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The six-member team URSinvestigators was one of 14 participants in the European Space Agency's CanSat-competition of 2016.

The challenge of creating a satellite simulation within the size and shape of a customary drinks can that had to fulfil the primary mission of measuring air temperature and pressure was completed by the self-chosen secondary mission of measuring air humidity as well as gathering an air sample for gas-phase chromatographical analysation during the post-flight activities.

The satellite fulfilled its mission to our satisfaction. During the test flight as well as the launch itself, its structural design as well as recovery system proved to work sufficiently. All regulatory requirements, including the descent rate of 11m/s, were met and our CanSat received little to no damage.

Due to data transmission problems with our self-constructed helix-antenna, we received very little data. With supplementation of radiosonde data from Lisbon, we were able to reconstruct the temperature and humidity in the atmosphere. The gas-phase chromatographical analysation of the air sample gathered by our satellite at about 700 meters' height showed a higher humidity compared to samples gathered on the ground, which correlates very well to the radiosonde data as well as our pre-launch studies.

* equally contributed

I INTRODUCTION

Inspired by the Rosetta mission, we decided to ask ourselves one of the most thrilling questions of humankind: Is there life outside of earth?

Since water is one of the most decisive evidences, we chose to measure the relative air humidity using a sensor as well as to collect an air sample employing a self-constructed triggering mechanism that was analysed gas chromatographically during our post-flight activities.

II PROJECT DESCRIPTION

II.I Materials and Structural Design

The structure of our satellite is a six level structure composed of seven separate parts. As our data transmission components and our triggering mechanism demand a certain height, these six levels are needed in order to fit them into the can. Furthermore, it enables to open the can without any difficulties which is essential for directly reaching the triggering mechanism and the battery.

The sensors are placed at the border of our satellite to ensure most precise data possible.

By means of SolidWorks, we modelled a mounting that appears to be a negative complex of the components in our satellite (see Fig. 1). This mounting was printed by our own 3D-printer and is kept together by rods (see Fig. 2). A CFK tube as the outer cover ensures the CanSat´s stability which is a major strength of our CanSat.

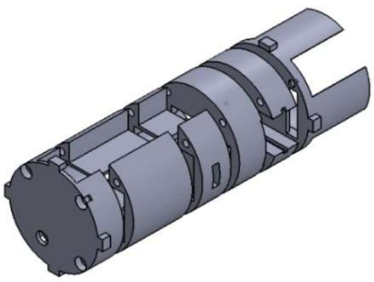


Fig. 1: 3D-model of CanSat, generated in SolidWorks

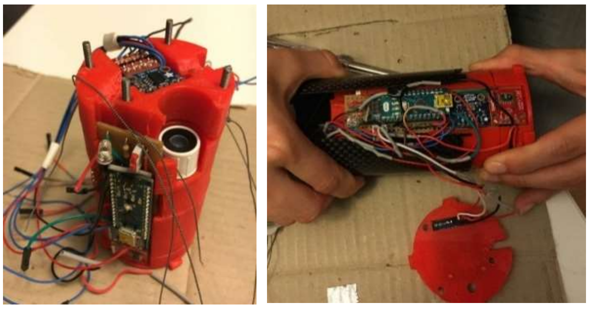


Fig. 2: structural design clearly visible in 3D-printed and completely assembled CanSat

Concerning our recovery system, we have designed our parachute as a relatively large round canopy parachute (see Fig. 3). It’s made of bright yellow kite cloth which enables us an easier search during the Launch Campaign. Moreover, its material is stable as well as tear proof. In order to reach 3,5N of force corresponding to a velocity of 11m/s, our parachute has one central hole and several smaller ones. Additionally, these holes provide a more stable flight without any spinning movements. To make sure that the parachute opens reliable and that the threads can’t twist too much, we employed a round plastic disc with four holes so that the threads can be pulled through these holes (see Fig. 4).

Fig. 3: the round canopy parachute

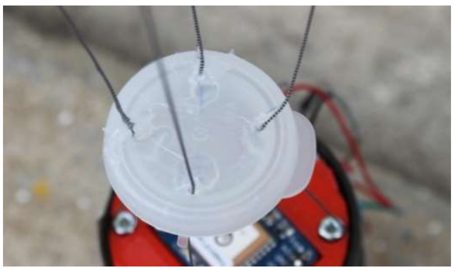


Fig. 4: the circular disk that prevents the cords from tangling

The second part of our recovery system is the GPS-module called Adafruit Ultimate GPS Breakout. Due to the fact that a huge part of our secondary mission such as the gas chromatographical analysis of the air samples is dependent on a successful recovery of the CanSat, it is an essential component of our CanSat. It enables us to determine the exact location of our satellite after the landing and increases the chance of a successful recovery.

II.II Software Design

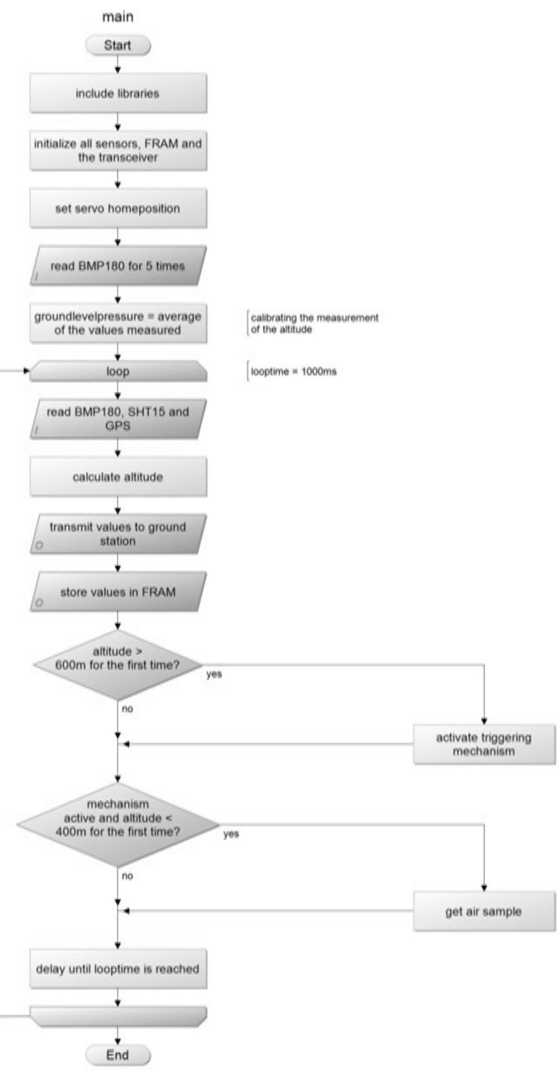


Fig. 5: program flow chart of the main code

In our software, we basically set all the needed regulations at first and then just let the program read all our sensors. In the setup, the servo was set to a predetermined home position and the zero level for height measurement was set by the BMP180 reading pressure 5 times and calculating the average of pressure.

Within the loop our CanSat read the data measured by our sensors and sent them to our ground station and should store them on the FRAM board.

The looptime was determined to 1000 ms.

The triggering mechanism was activated at a height of 800 metres and released the air sample if the CanSat fell under 400 metres again.

II.III Data Transmission and Antenna

For ensuring a good data transmission we built a helix antenna within the preparations for the German launch campaign. The antenna has a total height of 82 cm and its reflector consisting of aluminium has a diameter of 86 cm. The helix itself is made of a copper wire, has a diameter of 23 cm and is 70 cm high. This model was supposed to meet our expectations by having an opening angle of nearly 360 degrees and not being dependent on the level of polarization of the incoming electromagnetic radiation. Additionally, it's range was evaluated to be about 1.3 kilometres.

Fig. 6: the helix antenna during the test flight on Wednesday, 23rd June 2016

As transmitters, we chose to employ the HK Pilot Transceiver Telemetry Radio Set V2. They are as small as they need to be to fit into our CanSat and have good characteristics of transmission, like being able to cover a long distance.

II.IV Triggering Mechanism

A proper procedure for successfully gathering our air sample is a prime mission goal. Therefore a sufficient triggering mechanism is essential. The basic method requires modified and pre-evacuated plastic containers, namely vacuettes (see Fig. 7), providing a negative pressure.

Due to the vacuum air is being drawn in through an optimized cannula. After the cannula is retracted, the thick membrane seals the sample very tightly.

Fig. 7: vacuette

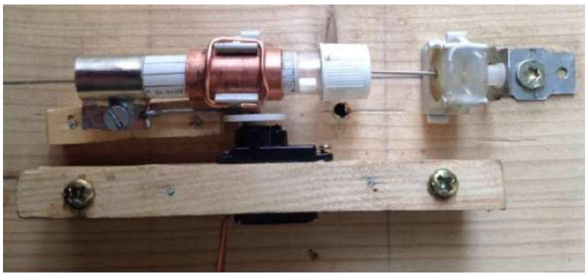


Fig. 8: preproduction model of the triggering mechanism

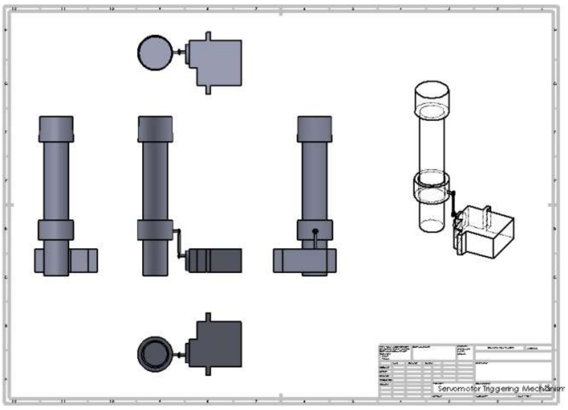


Fig. 9: SolidWorks model of the triggering mechanism

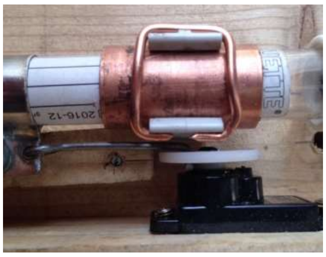


Fig. 10: connection rod

The puncture and retrieval is realized employing a servomotor whose rotation is converted into a linear vertical movement of the vacuette, which is guided through a mounting.

This conveyance is ensured by a connection rod that is attached to both, Vacuette and servomotor.

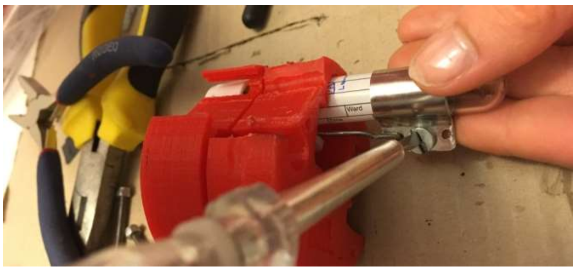


Fig. 11: the triggering mechanism after the CanSat's recovery on Friday, 24th June 2016

Analyzing the servomotor's position as well as the membrane's surface after the launch, it is certain that the mechanism worked.

Regarding the received information concerning our software, the mechanism has been prepared and triggered which strengthens our primer visual observation. Consequently, an air sample has been taken in the height of about 700meters and the gas chromatographical analysis is enabled.

II.V Gas Chromatography

Gas mixtures like air can be separated and quantitatively analyzed by gas-phase chromatography. During our preparations, we have adapted a low-cost self-construction kit designed and tested by Dr. Oliver Happel from AATIS e.V. to our purpose.

Cooperating with Dr. Oliver Happel, we firstly replaced the carrier gas with helium, as the suggested air would be insufficient for our mission. Consequently, the diaphragm pump had to be replaced by one with an aspiration port and linked to a medical urine bag that contained the helium.

The mobile phase of our gas-phase chromatograph (see Fig. 12) now consists of the carrier gas helium and an air sample that is injected with a syringe. The separation column is made of a very spongy material, diatomaceous earth, on which the stationary phase, a thin layer of paraffinic hydrocarbons, is applied. A small diaphragm pump (day power LP27-12) creates a pressure of 600mbar and provides a stable flow of carrier gas and sample.

Different polarity of the molecules in the sample mixture results in different interactions with the stationary phase. Polar molecules weakly interact with the nonpolar stationary phase whereas nonpolar molecules interact strongly (due to the Van Der Vaals forces). Because of that, polar molecules elute the column faster than unpolar molecules, resulting in a particular retention time that is characteristic of each substance.

A detection unit then quantifies the thermal conductivity in the gas flow and registers any changes employing a wolfram spiral (out of a small filament lamp) as detector that is linked to a Wheatstone bridge.

Data transmission to the PC is carried out by the measuring device that is used as analog digital converter, for data processing and data output. The microcontroller AVR MEGA328 is built-in an Arduino-Nano replica. The analog digital converter is used for signal enhancement with a resolution of 80 data points per second.

The open-source firmware AS646quant and UniChrom allow for graphic representation and

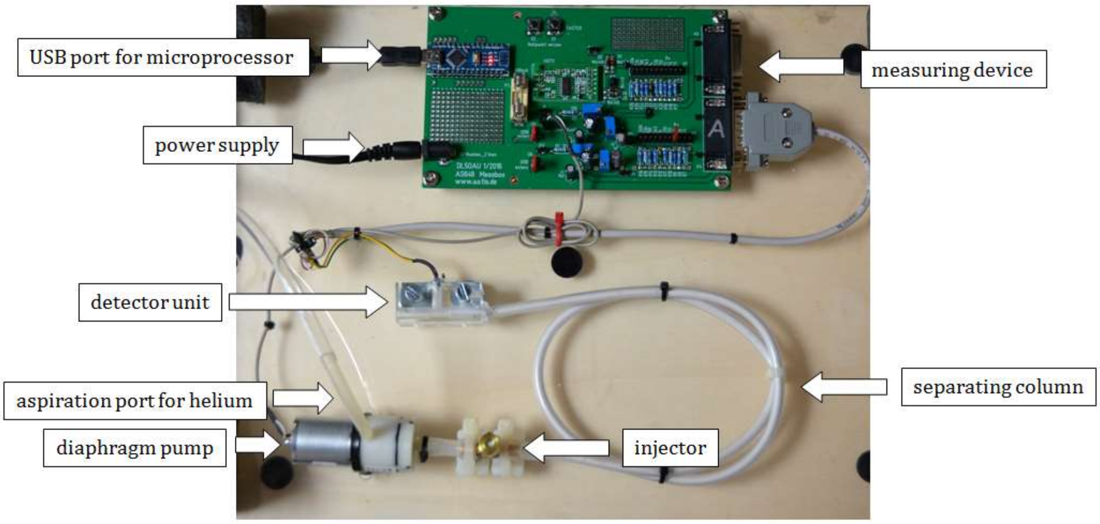


Fig. 12: our gas-phase chromatograph

data evaluation.

Comparing chromatograms of humid and arid air, there can be found a connection between the chromatogram's size and shape and the sample's relative air humidity that is simultaneously measured by our sensor SHT15. Our pre-launch studies and calibration show that in general, dry air tends to result in a larger surface area as well as a higher peak than humid air (see Fig. 13 and Fig. 14).

Consequently, any investigation of a sample and comparison to data of samples with known humidity is of a satisfying accuracy.

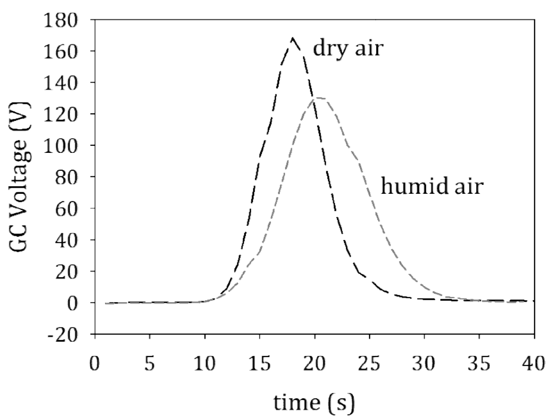


Fig. 13: comparison of chromatograms of dry and humid air samples

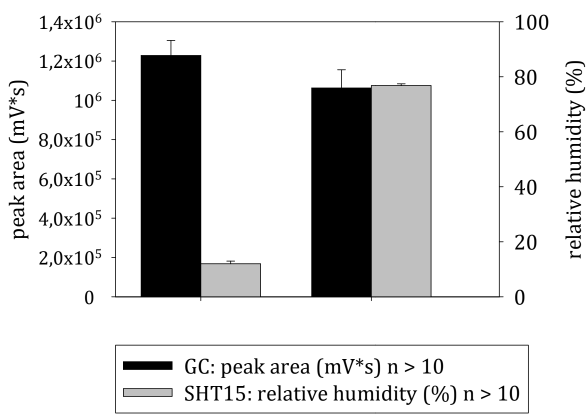


Fig. 14: comparison of surface areas of chromatograms of humid and arid air samples

III SCIENTIFIC RESULTS

III.I Data Transmission and Sensor Readings

During the launch of our CanSat, we had problems with the data reception. We received data until our CanSat reached a height of about 600 metres while it was still inside the rocked that launched it. 137 seconds later, after its landing, we received data again and were able to recover the CanSat with its GPS data.

This time-height diagram displays the data we have received from the CanSat. 1620 seconds after we turned our CanSat on, it reached the height of 601.05 m. Within the following 4 seconds we received the information that the air sample was activated. Due to the programme, this conveys the information that the CanSat had been over 600 metres 2 times which enables us to add a possible continuation for some seconds after the last complete package of data we received.

When we received the next package of data our CanSat had the height of 24.39m above its zero level, its final height. Therefore it must already have landed at that time.

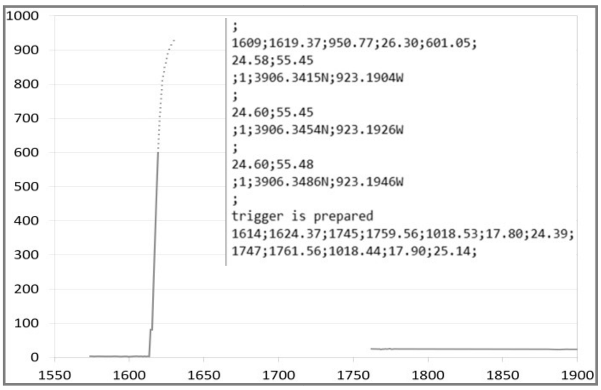


Fig. 15: height profile of our primary mission data [y-axe: altitude in meters | x-axe: seconds since turning on the CanSat]

III.II Gas Chromatography

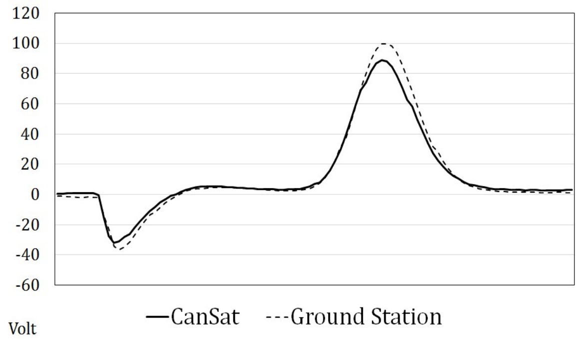


Fig. 16: comparison of the launch sample to the ground level air

These are the graphic results of our post-flight gas chromatographical analysis.

The chromatograms in Fig. 16 clearly differ in regard to their appearance and peaks. While the Ground Station's peak appears very high, the CanSat's peak is a lot lower, indicating a much higher air humidity in the atmospheric layer at the altitude of around 700m where the sample was taken than at around 0m.

In order to profoundly analyse our results, we relied on the air humidity readings of our sensor SHT15. As we did not receive any data from an altitude of above 600m, we had to use a database provided by a radiosonde near Lisbon (see Fig. 17).

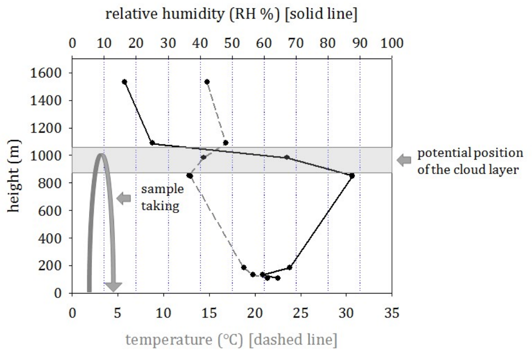
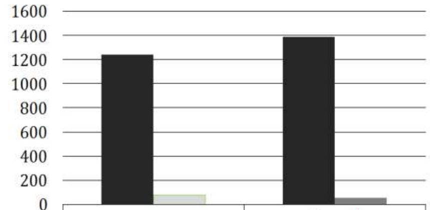


Fig. 17: database of relative air humidity and temperature provided by a radiosonde near Lisbon

The humidity profile shows a relatively constant rise in relative air humidity up to 850m. Then, a rapid decrease indicating strong condensation that can usually be found in clouds, is visible. Consequently, we assume that the cloud layer was at this altitude. The air sample was gathered at an altitude of about 700m. The graph indicates a relative air humidity of 80-85% in contrast to the relative air humidity of 55.92% we measured at our ground station, reassuring our assumptions based on the chromatograms.



	CanSat	Ground Station
Surface Area in Vs	1240,0023	1390,0228
Relative Air Humidity in %	80	55,92

Fig. 18: comparison of the surface areas of the chromatograms of the launch sample and the ground level air

Taking these observations into account, the (estimated) air humidity and the chromatogram's surface area also correspond in the way that was indicated by our pre-launch calibration, resulting in a smaller surface area for higher air humidity (see Fig. 18).

IV DISCUSSION

IV.I Failure of Data Transmission

The antenna had been one of our biggest obstacles which led eventually to our weak data transmission. Therefore, we tried to find and analyze the possible causes of this problem.

During the pre-launch, the alignment of our antenna was very difficult due to the steep descent to the rocket's starting place. We were able to solve this challenge by using a table which increased our antenna's mobility and therefore improved the data reception.

During the launch, the rocket disappeared in a cloud cover so that we could not align our antenna optically. An accurate alignment became more important when the distance between our antenna and the ground station had increased.

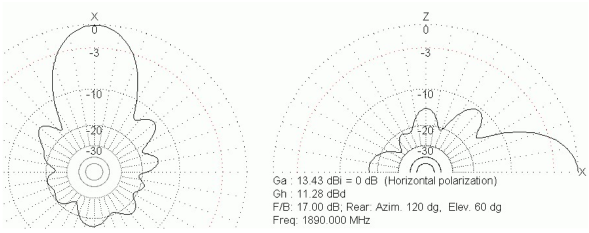


Fig. 19: the helix antenna's directional variance depending on distance

However, since our antenna's directional characteristic comprised 10.27dBi, the previously wide opening angle decreased and became sharper by increasing distance.

Out of our CanSat's GPS coordinates, we calculated the distance between our ground station and the CanSat. Eventually, it included a distance of about 1907m (see Fig. 20).

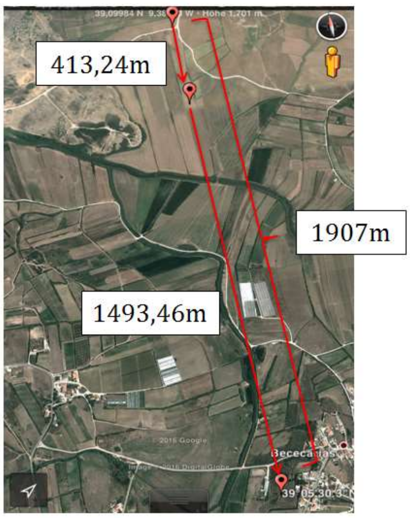


Fig. 20: distance of our CanSat and ground support equipment

During the launch preparations, we tested our antenna to a distance of up to 1500m (without movement) which seemingly was insufficient. As the maximum legal transmission is 10milliWatt, the distance was too high without good alignment.

During the landing, we finally received data again despite the long horizontal distance since our CanSat's position was static.

Summarized, our static antenna was not able to provide a tracking as accurate as needed to receive all data. The former evaluated opening was smaller than expected.

We have never tested the antenna's vertical and horizontal movement in a distance that is large enough.

Finally, we learned out of these problems that our antenna, despite all its qualities, was not the perfect model for this operation.

IV.II Relevance of Sensor Readings

Scientifically, the data that we were able to receive are comparatively irrelevant concerning their significance for the CanSat's descent as they only describe its ascent inside the rocket and descent below 80m. Consequently, they do not deliver any relevant information in regard to height, pressure, temperature and humidity during the descent.

Nevertheless, humidity measurements performed at the ground station were essential for the analysis of our air sample. Furthermore, the quality of the received sensor data can be stated as good since the measurements were realistic and reliable.

IV.III Evaluation of Chromatograms

As a realistic and clear result of our gas chromatography is obtained, one can consider this mission a real scientific success.

Generally, successfully taking air samples as well as analysing them gas chromatographically as a part of a satellite's mission can lead to major scientific findings. The possibility of life can be determined as the composition of the atmosphere indicates conditions as well as the elimination of life.

Having the possibility of taking multiple air samples at different altitudes due to a more complex satellite in a real space mission, one could conclude the structure of the atmosphere. To give an example, assuming the presence of water, a constant thick cloud layer that can be detected employing our method would have an influence on the life at the surface. Thus, developments and conditions on the planet's surface can be partly explained based on the investigation of the atmosphere gathering air samples and measuring air humidity. Consequently, gas chromatography is relevant for every single space mission in order to scientifically reason life conditions as well as successfully investigating a planet.

A point of contention might be that this particular investigation cannot be regarded as a completely correct comparison due to different temperatures and other environmental factors that have an impact on air humidity and cannot be recreated after the collection of the sample. The clear tendency, however, might still be uncontroversial.

The apparent connection between an air sample's humidity and its thermal conductivity that is linked to the surface area of its chromatogram might be to explain based on the fact that in a gas mixture, huge molecules move slower than smaller ones, resulting in a smaller thermal conductivity. In this context, it seems to be logical that a comparatively huge molecule like water will result in a smaller thermal conductivity and thus in a smaller surface area of a sample's chromatogram.

V CONCLUSIONS

During the last two years and especially the few months just before the Launch Campaign in Portugal, we turned out to be a strong team supporting each other in any case. By working hard in order to develop our CanSat, we have learned to coordinate and distribute our work in the long term which was especially important for writing our design reviews as well as focussing on each part of our mission. On account of the different abilities of every single team member, each of us specialized in one part of the mission and became an expert regarding her working field. Furthermore, the communication within the team worked well so that we were able to amass all ideas.

As we were able to win the second place in the European CanSat- Competition 2016, we can conclude that we jointly created a complex and thought-out mission, carried out good public relations work as well as presented our project in our design reviews quite well. At the end of the project, we realized the enormous importance of team work. Not only the communication and harmonious cooperation within the own team is essential but also the cooperation and camaraderie with the other participating teams.

During the preparations, several problems arose such as the construction of a proper triggering mechanism or the transportation of our helix antenna. In most instances, we noticed that there isn't enough time to solve these problems throughout our common and regular meetings within the school week so that we had to additionally spend the weekend working on the project. Thanks to our high ambitions, we solved these problems just in time.

Nevertheless, our high ambitions might also represent a weakness of our team. They have to be adapted to not only our abilities, but also to the available time. We also recognised that it is essential to find a realistic balance between innovation and proven technology.

Moreover, we learned that being prepared for several different circumstances as well as carrying out more tests is of a high importance in order to successfully accomplish a mission as not considering possible circumstances and developments hindered our project. Giving the example of our antenna, we took the lesson that our antenna has not been a perfectly suitable model for this operation which we should have detected prior to the launch campaign.

Finally, we are thankful that we were able to take part in the European CanSat Competition. Apart from content-related achievements and the acquisition of knowledge, we learned a lot about teamwork as well as documenting and presenting the own project. It was throughout the competition that some of us discovered their interests and ambitions. For each one of us, it was a great and enriching experience that will definitely help us in our future professions.

VI ACKNOWLEDGEMENTS

At the end of our enriching experience of the last one and a half years, we would like to say thank you.

On the one hand, to our sponsors and parters who supported us with material and advice that were essential for us to build up our performance. We would especially like to highlight Dr. Gert König-Langlo, Dr. Oliver Happel and Dr. Oliver Kuechemann for their advice concerning our gas chromatography as well as Mr. Professor Kronberger and his team from the TH in Cologne for their support in the construction of our helix-antenna.

To ESA, the jury and the local organisers at the airfield of Santa Cruz who gave us the possibility of participating in this competition and of gaining all the experience that we have collected so far.

On the other hand, to the all the other CanSat teams we spent these days with as well as to our families and friends. We are lucky to have experienced a lot of encouragement and cooperation.

And, most importantly, to our supervising teachers Raimund Servos and Dr. Petra Censarek who helped us out whenever we needed them and gave us advice in the way possible. Special thanks also to Mrs Springer who was our additional supervising teacher in Santa Cruz.

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