Fly a Rocket! ESA's hands-on programme for undergraduate students

Claudia Guerra[1], *Sam Beckers*[2], *Arthur Tavares Quintão*[3], *Jakub Zemek*[4]

Abstract

The Fly a Rocket! programme is a hands-on project offered by the European Space Agency's (ESA's) Education Office in collaboration with Andøya Space Education and the Norwegian Space Agency (Norsk Romsenter). The programme represents a unique opportunity for entry-level university students from diverse backgrounds to build, test, and launch an actual sounding rocket and obtain otherwise unattainable practical experience. In September 2020, the ESA Education Office announced the third edition of the programme, for which 30 students from the ESA Member States and the Associate Member States were selected. Of these, 24 participated in the launch campaign which took place throughout the second week of October 2021 at the Andøya Space in Northern Norway. The Fly a Rocket! programme comprises an online pre-course with two assignments and a hands-on launch campaign. The pre-course is self-paced and aims to widen the participants' understanding of basic rocket science topics such as the rocket principle, aerodynamics, and orbital mechanics in preparation for the campaign. During their stay at Andøya Space, the students were assigned to one of three teams, each with different responsibilities: Sensor Experiments, Telemetry and Data Readout, and Payload. As members of the Telemetry and Data Readout team, the authors' role was to set up the student telemetry station and ensure that accurate data was collected from the sensors on the rocket. In addition, they were an integral part of the countdown procedure, operating two of the three telemetry stations used for the mission. Following the launch, all the teams worked in conjunction to analyse and present the data according to four previously defined scientific cases.

This paper will be concerned with the activities carried out throughout Fly a Rocket!'s third cycle, with a particular focus on the work done by the Telemetry and Data Readout team.

Keywords

Andøya Space, ESA Education, sounding rocket, telemetry

[1] Corresponding author: University of Naples "Federico II", Italy, claudia.guerra2001@gmail.com
[2] Leiden University, The Netherlands, sam.beckers@outlook.com
[3] KU Leuven, Belgium
[4] University of Manchester, UK, jakub.zemek@student.manchester.ac.uk

Acronyms/Abbreviations

AS	*Andøya Space*
ESA	*European Space Agency*
FaR!	*Fly a Rocket!*
GPS	*Global Positioning System*
IMU	*Inertial Measurement Unit*
ISA	*International Standard Atmosphere*
KDE	*Kernel Density Estimation*
NRZ-L	*Nonreturn to zero-level*
RC	*Range Control*
SNR	*Signal-to-Noise Ratio*
TM	*Telemetry*

1. Introduction

The Fly a Rocket! (FaR!) programme is a European Space Agency (ESA) hands-on programme targeted at undergraduate students pursuing degrees in science and engineering.

The authors were among the 24 students selected to participate in the third cycle of the programme. FaR! comprises a pre-study course with assignments and a launch campaign at Andøya Space (AS).

During the launch campaign, the participants were divided into three teams. The authors of this paper were assigned to the Telemetry and Data Readout team, and they had the responsibility to ensure a good and complete reception of data from the rocket. Furthermore, all students were asked to define various scientific cases to investigate with the obtained sensor data.

This paper will present the Fly a Rocket! programme as it took place between November 2020 and October 2021, as well as an overview of the activities, conducted by the Telemetry and Data Readout team throughout the campaign.

2. The programme

2.1. Application Process

The call for applications to the third cycle of the programme was open between September and October 2020.

The call was aimed at students in the first two years of an undergraduate degree from an ESA Member State, Canada, Latvia, Lithuania, or Slovenia. Although interest in technology and space is crucial for participation in the programme, students from backgrounds other than aerospace were encouraged to apply.

As part of the selection, the candidates were asked to express their motivation to be part of the programme, as well as to propose outreach activities pertaining to the opportunity and an additional sounding rocket payload.

2.2. Pre-course and assignments

To ensure that every participant would have a basic understanding of the science behind rockets, 30 selected students had to complete a pre-course. The pre-course included a publicly available compendium and assignments.

The provided material encompassed various rocketry topics such as rocket engines, rocket dynamics, orbital mechanics, and telemetry. Detailed descriptions of the sounding rocket used in the campaign and its payload were also part of the course.

The assignments were divided into two mandatory parts and an optional third part, added after the campaign's postponement due to the COVID-19 pandemic. The exercises were made to thoroughly assess the students' understanding of pre-course topics, focusing not only on the straightforward calculations but also on the reasoning behind the answers.

During the months leading up to their stay at AS, the participants worked together on the pre-course material and assignments, allowing them to acquire the solution and to get to know each other before the launch campaign.

3. The campaign

3.1. Overview of the rocket

The student rocket is a Mongoose 98 rocket that has been customized to fit the student campaign didactic goals; it is 2.708 m long, 102.8 mm wide [1], and mostly made of carbon fibre. In the front is the glass fibre nose cone that optimizes the antenna gain, followed by the carbon fibre avionics tube, the aluminium avionics plate, and the carbon fibre booster tube with three fins in the rear.

The battery, encoder, transmitter, and sensors are mounted along with the aluminium avionics plate. The battery module is only used during flight. Before that, all setup and tests are carried out with the help of an umbilical connector. The encoder samples both analogue and digital sensors and outputs them in a Bi-Phase modulated Manchester code signal. This means that both data and clock are in one signal, and it reduces data rate drop and helps the ground station to lock onto the signal after a dropout. From the encoder, the signal is sent to the FM transmitter board. The frequency used in the student rocket is 2279.5 MHz with a transmitted power of 450 mW by two S-band antennas. During the Fly A Rocket! campaigns, a basic sensor kit is always flown on the rocket:

- two-axis accelerometer
- two temperature sensors
- pressure sensor
- light sensor
- two-axis magnetometer
- Global Positioning System (GPS)
- Inertial Measurement Unit (IMU)
- Temperature array

The sensors' locations on the plate were decided based on the scientific cases the campaign tackled.

3.2. Breakdown of activities

The launch campaign took place on the scenic island of Andøya in northern Norway where the students were hosted by Andøya Space, an aerospace company with over six decades of operational experience in sounding and suborbital rockets of various configurations.

Between Sunday, 10th, and Saturday, 16th of October, the students set up the Mongoose 98 rocket, learned about scientific rocket campaigns, atmospheric physics, rocket engines & trajectories, and the other ESA educational programs.

Day 1 - Arrival day, welcome and practical information.

Day 2 - Introduction to scientific rocket campaigns, a tour of Andøya Space, and selection of PI-team & responsibilities.

Day 3 - Rocket Integration & telemetry setup, lecture about Andøya Space, lecture about balloons & radiosondes, and the release of the first meteorological balloon.

Day 4 - Final rocket integration & telemetry setup, lecture on operative rocket range work, and presentation about other ESA educational programs.

Day 5 - Launch day, lecture about rocket engine and live demonstration, lecture on rocket trajectories, lecture on Andøya's ALOMAR, the release of the pre-flight meteorological balloon, and post-flight data analysis.

Day 6 - Data analysis, lecture on Aurora physics, preliminary presentation, and end of the campaign.

Day 7 - Departure day.

3.3. Scientific cases

The participants were given the task to formulate multiple scientific cases that would focus on various aspects of the rocket's flight, measured by the rocket's payload. The Sensor Experiments team was divided into smaller groups that were each assigned a different scientific case.

The first scientific case (three members) used the balloon, temperature sensor, GPS, pressure sensor and optical sensor to detect the entry, exit and thickness of clouds. They hypothesized that detection of clouds can be performed using an optical, temperature or humidity sensor. Moreover, they thought that detection of clouds with the optical sensor would be the most accurate method.

The second scientific case (eight members) aimed to find out which method would provide the most accurate location of the rocket. The data was compared to the Open Rocket model, which estimates the trajectory of a rocket given its specifications. They hypotheses were:

- Open Rocket will be accurate up to Mach 1, where it is expected that the real values will deviate from the simulation
- At supersonic speed, GPS is expected to be the most accurate
- The IMU will likely drift over time due to its sensors experiencing noise.
- The pressure sensor is expected to provide valid results but the accuracy of these may deviate due to external wind from the holes of the rocket.

Detailed plots were created that compared the data from the GPS and pressure sensor to the data from Open Rocket for the scientific rocket. Unfortunately, the IMU data was lost due to sensor failure.

The next scientific case (two members) used the balloon, pressure sensor and external temperature sensor to collect atmospheric temperature and pressure measurements at different altitudes from the balloon and the rocket. These measurements would then be compared with the International Standard Atmosphere (ISA). The team hypothesized that:

- As altitude increases, atmospheric pressure is expected to decrease following a specific trend.
- At a given altitude, the temperature measured outside the rocket is expected to be higher than ISA/balloon measures.
- At a given altitude, the pressure measured outside the rocket is not expected to reflect the exact atmospheric pressure but should be close to it.

The team was not able to recover GPS data, but it was able to collect pressure data.

The final scientific case (three members) had the objective to determine the spin of the rocket using three methods - light brightness variation, magnetic field strength variation and accelerometer data for the y-axis. The team wished to achieve this using the optical sensor, the accelerometer, and the magnetometer. Their hypothesis was that there is a direct correlation between the acceleration in the direction of travel and the spin of the rocket. Moreover, the direction of the spin would stay the same the entire trajectory (even if the acceleration changes direction in the axis of travel) as the fins are canted.

4. Telemetry and Data Readout

The Telemetry and Data Readout team was composed of 4 members and supervised by two Andøya Space Education teachers. The students were handed out booklets with theory and instructions and familiarized themselves with all aspects of telemetry station operation.

4.1. Setup of the student telemetry station

The hardware of the student telemetry (TM) station, which was set up by the team, includes an antenna, a downconverter, two receivers (for right- and left-hand polarization), a bit-synchronizer and a combiner [2] shown in Figure 1. Additionally, the TM station rack is connected to a DEWESoft decoder unit which feeds the data into a computer. The TM team had to arrange both the wiring and the settings of the rack. To perform this task, the members were divided into two groups, and each was assigned one of the two sides to work on. Once finished, the two groups switched roles so that each student could become familiar with every task. This gave the students an unprecedented opportunity to connect their theoretical knowledge of data transmission with practical experience operating actual hardware.

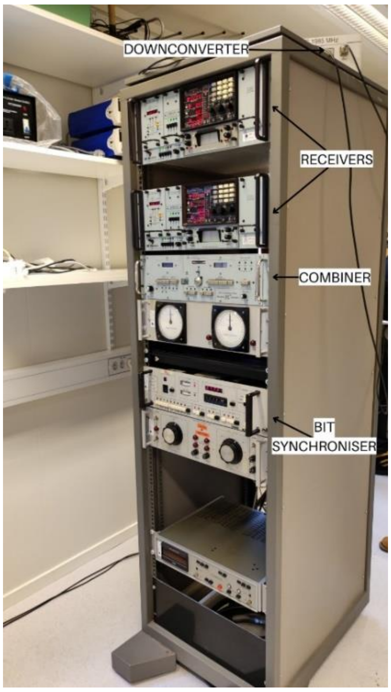

Figure 1. Student telemetry rack

To demultiplex the incoming data from the student rocket, the TM team used two DEWESoft decoders and their associated software. The decoder is connected to the Non-Return-to-Zero-Level (NRZ-L) and clock cables coming from the Bit Synchronizer as well as to a laptop where a setup file decodes the signal into multiple channels that can be recorded by the DEWESoft X3 program. Ultimately the goal was to save and export the data to .CSV files that could be analysed by the Sensors team using a Python script.

4.2. TM and Data Readout role during launch

During the launch day, the students from the TM station were assigned two roles called Student TM and TM Readout with 2 students in each sub-team.

The TM Readout operated a DEWEsoft box connected to the antenna of the Main TM station and was the main source of communication between telemetry and the Range Control (RC) and Payload Manager.

The Student TM had their DEWEsoft box connected to the instruments at the student telemetry rack situated in the Andøya Education telemetry lab, where the students had worked in the previous days.

5. Discussion

5.1. Challenges during the countdown procedure

During the countdown procedure, the RC, the Student TM station, and the TM Readout performed a data storing test and found that the TM Readout team was not receiving any sensible data at that point. The countdown was paused, and the two telemetry stations worked closely together to resolve the problem However, since the TM teams suspected the problem to be the TM Readout's DEWESoft decoder, the team concluded that the countdown procedure should continue and that the data would be received and stored only by the Student TM station and Main TM.

After splashdown, once the recording was stopped and the data was saved, the TM and Data Readout team noticed that the data stream recorded at the Student TM station was very noisy and had a high number of frames missing. A possible cause is that the student antenna pre-set motion failed to track the rocket in real-time causing the station to lose data. Fortunately, the post-processing filtering was enough to provide enough data for the teams to work on their scientific cases and the Main TM station also provided cleaner backup data from the flight. These hindrances highlighted the importance of redundancy in the telemetry system.

5.2. Scientific cases outcomes

From the analysis of the scientific cases, the following conclusions were made:

- The first team managed to identify clouds with the sensors and compared the results to a cloud distribution model, concluding that the optical sensor gave the most accurate results.
- The comparison of acceleration, apogee and velocity showed that there was little deviation between the different methods and Open Rocket, thus proving that Open Rocket provided a surprisingly accurate trajectory.
- The third team found that the pressure data gave a good approximation. However, due to Andøya's location in the Northern atmosphere and due to time of year it was concluded that the 1993 ICAO standard atmosphere was not the best model for the atmosphere in question.
- The fourth team concluded that both the magnetometer and the optical sensor provided good data for a spin and that the spin was at its highest during the first ten seconds, and at its lowest at apogee. The spin of the rocket did not change direction after the apogee

The scientific cases were sometimes difficult because some of the data had a lot of noise and interpreting it correctly was often challenging for the teams. However, in the end, solid conclusions were obtained, and most hypotheses were confirmed.

5.3. Learning outcomes

Actively taking part in international scientific cooperation was one of the main goals this educational programme tried to achieve. Working together on the scientific cases, as well as on the payload integration and telemetry setup, provided for the most exposure to international cooperation most participants had ever experienced. Teamwork was paramount for solving the challenging problems that were presented to the teams and the Andøya staff strongly encouraged them to use the best elements from each person's skillset to solve said problems. If the team ran into problems, they were eager to call for each other's help and see if another perspective on the problem could enlighten them and provide a path to the proper solution. It was astonishing to see how a group of strangers from various countries was able to form an efficient and effective team in only one week, putting their bright minds together and successfully launching a scientific sounding rocket. International scientific cooperation was most definitely an achieved learning outcome.

Moreover, ESA wished to show the participants what working at an active rocket launch site would be like and to give us a glimpse at a potential future working at an international space agency. By introducing them to Andøya Space, they allowed the participants to experience first-hand how an active launch site and research facility operates. The lectures that were given during the week provided the team with a theoretical background that is often valuable in this field. Being able to walk around the facility gave the students the most accurate representation of what working at such a facility could be like. Most importantly, being able to actively take part in a rocket campaign showed them what it is like to launch a rocket, albeit on a smaller scale and with more limitations due to safety precautions. Nonetheless, it paralleled what the team might expect to experience in the future when given an opportunity to work in the field.

The TM and Data Readout team specifically had a crucial role in this, being the responsible team for making sure the data from the rocket was properly received and processed, enabling the other teams to analyse it. The responsibility of this task gave a good indication of what is expected from scientists at a rocket facility.

5.4. Future work

A possible area of future work involves further analysis of the recorded data by calculating the Signal-to-Noise Ratio (SNR) and applying Kernel density estimates to reduce the noise and "to reconstruct a continuous distribution from a discrete point set", which is the collected dataset. [3]

The SNR ratio is an important measure of signal quality and compares levels of noise and signal. By using a computer programme, it would be possible to sensibly discretise data from the rocket to intervals and calculate SNR for each interval. The result could be then plotted against time and compared with the rocket flight path telemetry antenna setting to better understand what could cause the noise.

Noise is a major concern when it comes to processing signals from a sounding rocket. Therefore, the scope of future work could focus on "proposing a new theoretical and algorithmic framework to evaluate and reduce the noise level" in the signal "based on the Kernel Density Estimation (KDE) theory" [4]. One of the key parameters of KDE is the bandwidth that influences the quality of the KDE. Since bandwidth in KDE is a free parameter, one of the potential areas of work could be dedicated to comparing the application of unit Kernels to Normalized Kernels.

6. Conclusions

After months of preparation, from applying to completing the pre-course and assignments, 24 students from all over Europe came together at AS for the launch campaign that represented the culmination of the third cycle of the FaR! programme.

Over a week, the participants got the unique opportunity to gain hands-on experience working at a rocket range and taking over the traditional roles needed to launch a scientific sounding rocket.

The authors of this paper were assigned to the Telemetry and Data Readout team, working on the setup of the student telemetry rack and of the software needed for obtaining good data stream. Overall, the programme gave them invaluable insights into the skills and knowledge needed to operate a telemetry station, as well as the importance of redundancy for the success of a scientific mission.

Acknowledgements

The authors want to sincerely thank the ESA Education Office and Andøya Space Education staff for the opportunity to take part in the Fly a Rocket! programme.

Additionally, C. Guerra and J. Zemek would like to further thank ESA Education for sponsoring their attendance to the symposium.

References

[1] NAROM student rocket pre-study: https://www.narom.no/undervisningsressurser/sarepta/rocket-theory/pre-study/, visited: 6th March 2022.

[2] Andøya Space Education, Telemetry Mission Manual.

[3] Y. Zheng, J.M. Phillips, L∞ Error and Bandwidth Selection for Kernel Density Estimates of Large Data, *21st ACM SIGKDD International Conference on Knowledge Discovery and Data Mining*, Sydney, 2015.

[4] W. Wu, H. Qin, Reducing noise for PIC simulations using kernel density estimation algorithm, *Physics of Plasmas*, 25, 2018.