Fly A Rocket! Programme: Assembly, Testing and Post-Flight Review of a Sounding Rocket Payload

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Abstract

The *Fly a Rocket!* programme is a hands-on project offered by the European Space Agency's Education Office in collaboration with Andøya Space Education and the Norwegian Space Agency (Norsk Romsenter). The programme, which comprises an online pre-course and a hands-on launch campaign, represents a unique opportunity for european university students from different backgrounds to build, test, and launch a sounding rocket and obtain practical experience. The pre-course strengthened the understanding of rocket science of the students, and taught them about topics such as the rocket dynamics, propulsion, and orbital mechanics in preparation for the campaign. The students were divided into three teams, each with different responsibilities: *Sensors Experiments*, *Telemetry and Data Readout*, and *Payload*. The paper will focus on the work done by the team responsible for the rocket payload. The *Payload* team was responsible for the sensor placement of the rocket. They ensured the readiness of all the sensors and key components of the rocket. In addition, they were an integral part of the countdown procedure, the arming of the rocket and the performance of the sensors. After the launch, the data was analysed and presented according to four previously defined scientific cases. A GPS and a barometer were used in order to obtain the rocket trajectory. Both methods showed similar results. The GPS detected an apogee of 8630.11 ±2.4m. With an optical sensor it was possible to detect clouds which were verified with a humidity sensor. Additionally, the spin rate of the rocket could be detected with the optical sensor and a magnetometer by doing a Fourier Analysis. The rocket reached a spin rate of about 19 Hz after approximately 10 s after the firing. The results of the spin rate correspond to the results obtained with an accelerometer.

Keywords
Payload, Sounding Rocket, Student Programme

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Nomenclature

a	*Acceleration*
ν	*Spin rate frequency*
ν'	*Time derivative of* ν
t	*Time*

Acronyms/Abbreviations

AP	*Avionics Plate*
AT	*Avionics Tube*
ISA	*International Standard Atmosphere*
PAS	*Pad Supervisor*
PM	*Payload Manager*
RC	*Range Control*
TM	*Telemetry*

1. Introduction

In October 2021, 24 bachelor students from universities all over Europe gathered at Andøya Space to participate in the *Fly a Rocket!* programme. This educational programme was organised by the ESA Education Office, the Norwegian Space Agency and Andøya Space. It was targeted to Bachelor students studying a STEM field.
The first part of the programme served as a preparation for the practical work in Andøya; the students completed tasks using orbital dynamics and rocket trajectory simulations. During this preparation time, the students had access to various documents providing information about the properties of rockets and their associated engineering challenges. [4]

Figure 1. Rear airframe (above) and avionics tube (AT) with nose cone installed (below).

The second part and most important part of the programme took place at Andøya Space. During one week, *Aurora*, a Mongoose 98 sounding rocket (2.7m) was assembled and launched. Additionally, multiple lectures related to space research were held by personnel from the space industry working with Andøya Space.

The students were split into three different groups working on the payload, the sensors, and the telemetry [1]. This paper will focus on the work conducted by the *Payload* team.

The payload of *Aurora* consists of a combination of different sensors. The *Payload* team was responsible for the proper integration of all sensors. Depending on the objective of a specific sensor, a suitable position inside the rocket had to be chosen. The sensors were placed onto an aluminium avionics plate (AP) which was fixed inside the upper part of the rocket as seen in Fig.2. Using the transmitted data of the flight, four scientific cases were defined and studied:

a) Comparison of different trajectory determination methods.
b) Detection of clouds through light intensity variations.
c) Determination of the spin rate of the rocket with different methods.
d) Analysis of the temperature gradient in the atmosphere.

2. Sensor placements discussion based on scientific cases

The placement of the sensors on the AT had a crucial impact on the data collected and the validity of the results. Placement priority was primarily based on the importance of the scientific cases corresponding to each of the sensors. This considered the impact of misplacing sensors and the limitations imposed by cable lengths.

It was necessary to place the optical sensor at a location where it would be exposed to daylight, therefore it was placed at the rear of the AP, located underneath two holes in the surface of the avionics tube (AT). The sensor was aligned asymmetrically with respect to the holes in order to allow a difference in light intensity from each of the holes, enabling the direction of rocket rotation to be determined.

The rocket structure was primarily composed of carbon fibre composite, which blocks and absorbs GPS signals. The nose cone was made out of GPS penetrable fibreglass. Consequently, the GPS board was placed at

the fore of the AP, with the sensor located in the nose cone.
The internal air temperature and pressure of the AT were measured using a temperature array and two pressure sensors. The pressure sensors were aligned in the same direction, away from holes in the AT. They were located at the upper and lower part of the AT in order to determine whether there would exist a pressure differential during flight due to supersonic shockwaves or otherwise, which would have an impact on the altitude measurement.

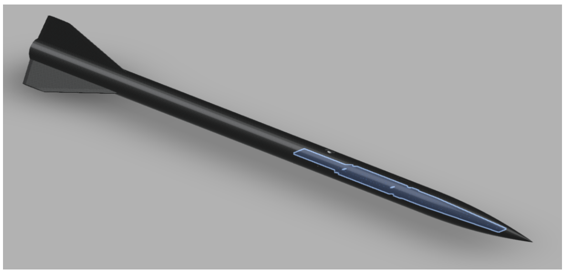

Figure 2. Mongoose 98 with integrated aluminium avionics plate (AP) in the upper part of the rocket.

The temperature array board was located slightly above the centre of the AP, with the individual temperature sensors connected along the length of the AP. Ideally they would have been mounted to the AT, however this was infeasible due to the requirement for quick rocket disassembly for the purpose of pre-flight balance and stability checks/adding ballast. An additional temperature sensor was placed beneath a hole in the AT to measure the 'external' temperature as accurately as was feasible.

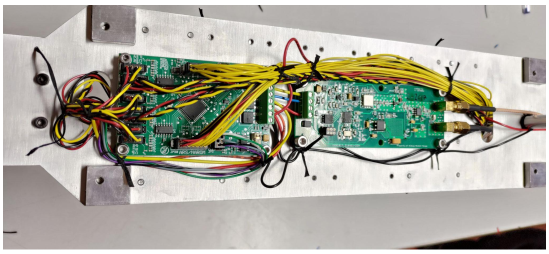

Figure 3. Encoder (left) and transmitter (right) on the back of the avionics plate.

The magnetometer required its measurement axis to be perpendicular to the longitudinal axis of the rocket. It was placed with the sensor as far as possible from the axis of rotation, at the aft of the AP.

The location of the on-board batteries and ammeter were determined by the position of the preinstalled battery mounts. The sensor data encoder and transmitter circuit board locations were predetermined, situated on the opposite side of the AP to the sensors (see Fig. 3), next to the transmitter ports in the AT and with access to the umbilical port for external power as seen in Fig. 6.

3. Sensors testing

Before testing the payload as a whole, individual tests were performed on each of the sensors, in order to determine the expected values during launch and to make sure that the output voltage would not exceed 5V, which was the upper operating range of the sensors.
The sensors in table 1 had the same testing set-up, as they all output analog information. The set-up consisted of a power supply of 5V (simulating the voltage input from the encoder) and an oscilloscope that read the voltage output. From these tests the following reference values were obtained, which were given to the telemetry stations to perform telemetry tests.

Table 1. Testing results for each sensor

Sensor	Expected Voltage Value when tested (Volts)
Accelerometer	2.5V at constant velocity (with a 0.04V and 0.02V raise per g on the x-axis and y-axis respectively)
Pressure sensors	4V at sea level pressure
Internal temperature sensor	1.16V at room temperature
External temperature sensor	2.82V at room temperature
Optical sensor	200mV: inside the tube 3.8V: exposed to natural daylight

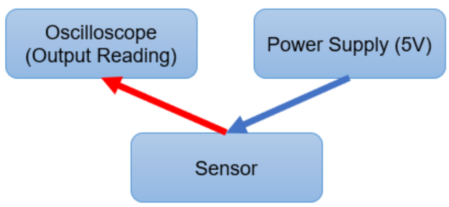

Figure 4. Testing set-up for analog sensors.

The three digital sensors (temperature array, GPS and IMU) had a different test setup from the analogue sensors. The sensors were connected to a board, which gave current to the sensor and received the output voltage, just as the encoder would do. Connecting the board to a computer, it was possible to analyse real-time data that the sensors collected.

The current sensor required another different test set-up; an oscilloscope detected the output from the current sensor, a power supply of both 10 V and 5 V simulated the internal batteries of the rocket, and a variable current load represented the intensity consumed by all the other payload sensors. The set-up is the following:

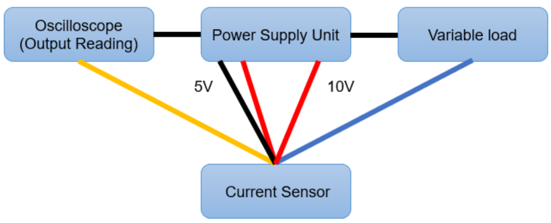

Figure 5. Testing set-up for the current sensor (In yellow the oscilloscope input from the current sensor, in blue the output of variable load to the current sensor and in black and blue connections between components)

4. Payload Assembly

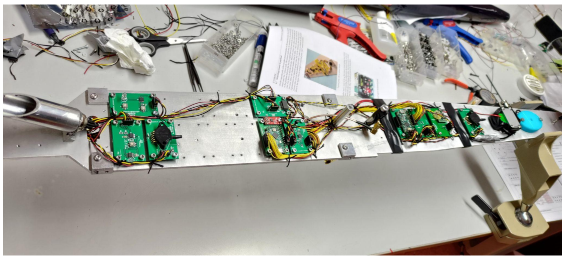

Figure 6. Payload plate with the sensors assembled. From left to right: magnetometer, optical sensor, pressure sensor (#1), IMU, temperature sensor, temperature array, current sensor, GPS, pressure sensor (#2), battery and GPS transmitter.

For all connections between different circuit boards, electric cables (AWG 26 wires) with suitable lengths were produced using a crimp tool and a female micro connector, and bound with cable ties [3]. The circuit boards were bolted into threads in the AP, with plastic washers placed between the AP and the circuit boards in order to avoid short circuiting between the sensor pins. The GPS sensor was secured to the payload assembly by bolting a 3D printed housing to the AP. After the sensors had been fixed to the AP, the AP was installed in the AT by Andøya Space staff prior to weight and balance checks.

5. Payload team role during launch

The payload manager (PM) was responsible for the functioning of the rocket's payload during launch. The PM was in constant communication with Range Control (RC) and the three Telemetry Stations (TM) ensuring smooth communication for a safe operation. The PM supervised the installation of the rocket on the launcher together with the Pad Supervisor (PAS), and asked for the confirmation checks of the sensors from the TM stations. Furthermore, the PM controlled the power supply of the rocket and armed the payload one minute before the launch [2]. No problems occurred during the operation and the launch was successful.

6. Results and Discussion

The four scientific cases presented in section 1 were analysed after the flight using the collected data.

6.1. Case a) Oliver Twist

Data from GPS, the top and bottom pressure sensor and IMU were used in order to calculate the rocket's altitude. It was assumed that the GPS data is the most accurate and was therefore used as a reference. The pressure data was converted to altitude using the International Standard Atmosphere (ISA) model. The data from the IMU was very noisy which is why it was not further included in the discussion.

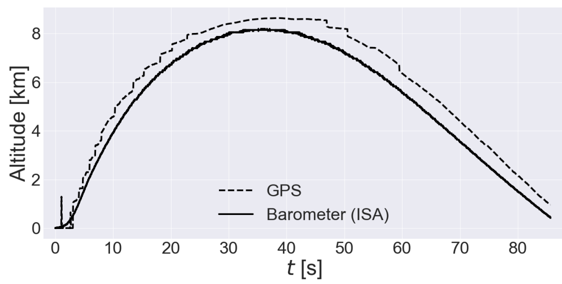

Figure 7. The rocket's altitude determined with GPS and two pressure sensors (averaged value).

Both pressure sensors showed similar results which suggests that the data is reliable. However, the aft pressure sensor in general showed slightly higher pressure values, which may be attributed to accumulated air at the rocket's payload bay. The fore pressure sensor showed similar results as the GPS.

6.2. Case b) Cloud Atlas

The objective of the scientific case Cloud Atlas was to detect clouds during the flight with three different methods. An optical sensor which detects the light density and humidity sensor.

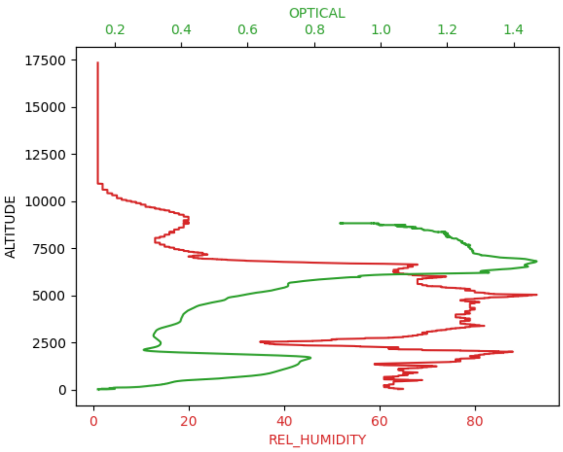

Figure 8: The humidity and the optical index as a function of the altitude. An optical index of 1 was used as reference for natural light. Data was obtained from a weather balloon released at Andøya Space.

A cloud should lead to high humidity values (close to 100%). The cloud would also lead to a lower light intensity since the cloud covers the sunlight.

Shortly before the rocket's flight, a weather balloon was released to measure the humidity and the light intensity. The humidity changed a lot until around 10 km as shown in Fig. 8. It was observed that the light intensity is small at altitudes between 3 km and 7 km. As expected the humidity is high in this range and therefore only little sunlight reached the optical sensor. The same explanation can be used between 7 km and 9 km where the humidity decreases and the light intensity increases.

The rocket did not have a humidity sensor and only detected clouds with the optical sensor. The obtained data during the rocket flight showed similar data curves as the data from the weather balloon shown in Fig. 8. Small abbreviations can be explained with a different flying direction and small changes during the 30 minutes of the launch times.

6.3. Case c) Rock And Roll

The spin rate of the magnetometer and the optical sensor were determined with a spectrogram shown in Fig. 9. The bright yellow line indicates the high amplitude of the corresponding spin rate.

The spin rate ν can be easier determined with an accelerometer perpendicular to the rocket's flight direction.

$$\nu = \frac{1}{2\pi}\sqrt[4]{\frac{a^2}{r^2} - (2\pi \cdot \nu')^2} \approx \frac{1}{2\pi}\sqrt{\frac{a}{r}} \qquad (1)$$

As an approximation, the second term in the root in the eq. 1 was neglected. The comparison to the results of the magnetometer and optical sensor showed that this approximation holds. Furthermore a distance between the accelerometer and the rotation axis of r = 3 cm was used. This value was estimated since it had not been measured before the flight. However, pictures of the payload and the comparison with the data obtained with completely different methods, validated this value.

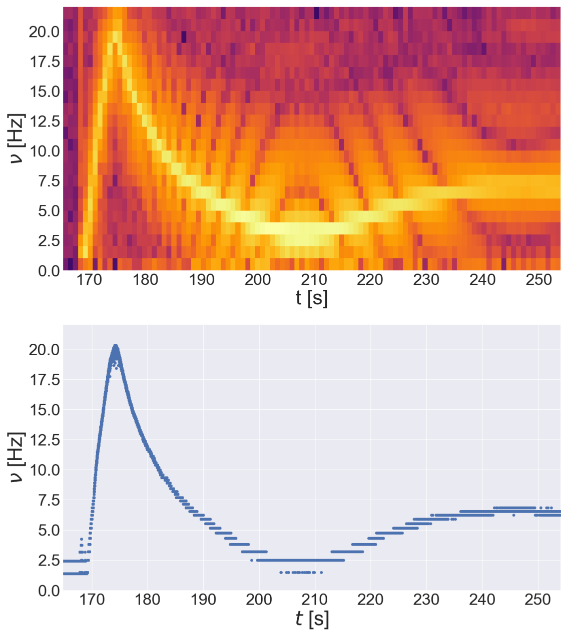

Figure 9: Visualisation of the rocket spin rate. Top: Spectrogram of the magnetometer data. Bottom: Spin rate calculated from the centripetal acceleration of the rocket.

The spin rate was the highest after the first 10 sec after the firing and reached a maximum value of around 19 Hz. The lowest spin rate of about 3 Hz was observed during the apogee. Using the method described in section 2 the spin direction was determined and it was shown that it stayed the same during the whole flight.

The optical sensor showed a less clear spectrogram than the magnetometer. The main reason for this phenomena is that the spin rate could not have been detected precisely whenever the rocket flew through a cloud since the cloud creates a homogeneous light which makes it difficult to detect periodic patterns. Outside the cloud the sun as a point source was creating the periodic light peaks.
The sensor placement of the sensors was therefore well chosen by the payload team.

6.4. Case d) 451 Degrees Fahrenheit

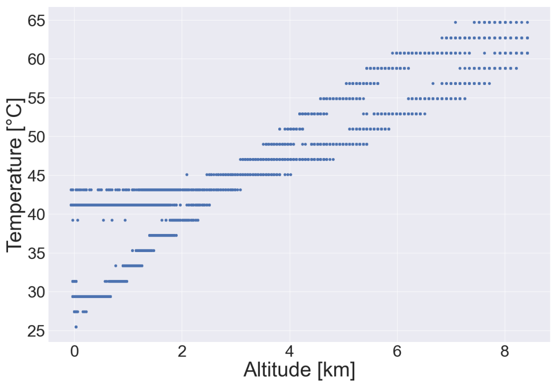

Figure 10: The external temperature as a function of the altitude of the rocket. The external temperature sensor was placed onto the fairing of the rocket.

An external temperature sensor and a pressure sensor were used in order to study the atmosphere. The altitude of the rocket was taken as pressure altitude. The 1993 ICAO Standard Atmosphere [5] was used but is not a perfectly suitable model since the location of Andøya in the upper northern hemisphere.

The results have shown that the temperature obtained from the *external* temperature sensor does not show any correlation to the 1993 ICAO Standard atmosphere model. The data in Fig. 10 shows that the temperature increased with increasing height which should be exactly the opposite using the ICAO model. The explanation of this behaviour is probably that the sensor encountered interference from the fairing of the rocket. The air resistance caused heating of the fairing during the flight and therefore an increase in detected temperature.
A weather balloon was released shortly before the rocket flight. The data showed a much better correlation to the ICAO model as shown in Fig. 11. Since the weather balloon flies much slower than the rocket, the results agree with the discrepancy of the rocket data.

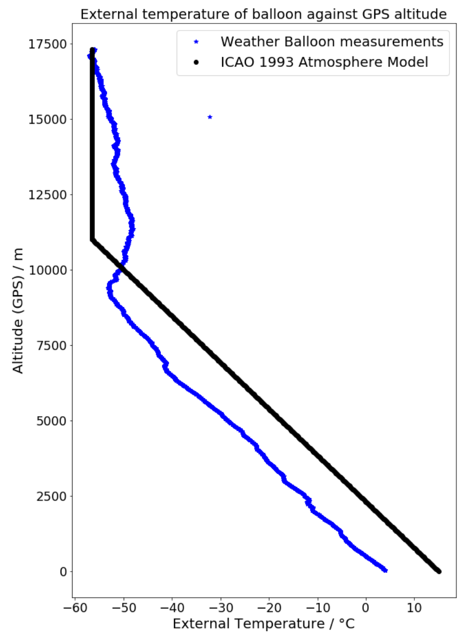

Figure 11: temperature measured from a weather balloon 30 minutes before the rocket flight.

7. Conclusions

During the launch campaign, the payload team's tasks included both soldering, making cables, and mounting and testing the sensors of the Mongoose 98 rocket. This required a wide range of knowledge as the payload had to work correctly in order for the telemetry team to receive data. The payload team also had the responsibility of verifying sensors, which was a big responsibility.

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