Lessons Learned when Developing a High Performance Attitude Controlled Platform to Achieve Microgravity for Low-Cost Experiments

Andreas Wolnievik[1], Noel Janes[2], Flavia Pérez Cámara[3], Ric Dengel[4], Diane Delley[4], Anne Hartmann[4], Paloma Maestro Redondo[4], Miguel Llamas Lanza[4], Erik Samuelsson[4], Íñigo de Loyola Chacartegui Rojo[4], Jonathan Lange[4], Elena Fernández Bravo[4], Cornelis Peter Hiemstra[4], Sebastian Scholz[4], Henning Isberg[4], Tõnis Kull[4], Spyridon Gouvalas[4]

Abstract

Available Attitude Control Systems are often targeted at orbital flights, and therefore manoeuvre slowly. As such, these solutions are suboptimal for sounding rocket experiments, as experiments such as those conducted on free falling units have restricted flight times. Furthermore, current attitude control systems are usually aimed at projects with extensive funding, and are therefore out of the budget range of low-cost experiments. Taking these constraints into account, the objective of project ASTER is to design and test a low-cost, fast-acting solution, to stabilise and orientate a free-falling platform, which is capable of providing microgravity conditions for experiments. The proposed design utilises three reaction wheels, controlled by a closed loop system, to stabilise the Free Falling Unit within seconds. The platform will be able to perform predefined slewing manoeuvres, which can be adapted to a wide range of applications. The free falling unit is a cube weighing around 3kg with a side length of 150 x 150 x 180 mm, with a recovery parachute system included. Designed to act as a system platform for free falling units, it will be able to accommodate future experiments, providing an easily adaptable payload bay with dimensions up to 56 x 91 x 77 mm. Furthermore, the system will be recovered after the experiment has been concluded and the results obtained will be published on an open source basis to ensure its future availability to other student and low budget research projects, thereby allowing further improvement, optimisation, and customisation. The experiment development began in September 2019 and is scheduled to fly on a sounding rocket in March 2023. Team ASTER wants to contribute to the student community by sharing the experiences and lessons learned during the project development, which is what will be focused upon in this paper and accompanying presentation.

Keywords
Attitude Control System, Free Falling Unit, Learning Project, Microgravity, Sounding Rocket

[1]Corresponding author: Luleå University of Technology, Sweden, Andwol-6@student.ltu.se,
[2] Luleå University of Technology, Sweden, noejan-9@student.ltu.se
[3] Luleå University of Technology, Sweden, flapre-9@student.ltu.se
[4] Team members: Luleå University of Technology, Sweden

Acronyms/Abbreviations

ASTER	*Attitude STabilised free falling ExpeRiment*
ACS	*Attitude Control System*
CDR	*Attitude Control System*
GS	*Ground Station*
EAR	*Experiment Acceptance Review*
EPS	*Electronic Power System*
FFU	*Free Falling Unit*
IPR	*Integration Progress Review*
OBDH	*On-Board Datahandling*
PDR	*Preliminary Design Review*
REXUS	*Rocket EXperiment for University Students*
RMU	*Rocket Mounted Unit*
RW	*Reaction Wheels*
LTU	*Luleå University of Technology*
SED	*Student Experiment Document*

1. Introduction

Microgravity is an important field of research, which is vital for the efficient future utilisation of space and helps to develop new technologies both for space and ground applications. Microgravity experiments can be undertaken on-orbit, however, this is often well outside the available funding range of student and low-budget experiments. More economical alternatives are offered by drop towers and parabolic flights, but these are instead constrained to short periods of sustained microgravity conditions. Performing microgravity experiments on sounding rockets provides a more accessible solution, while still allowing for periods of microgravity in the order of minutes rather than seconds. However, unless entirely stabilised, such experiments cannot achieve true microgravity conditions due to residual external forces, such as the centrifugal force of the rocket's spin. A solution to eliminate the remaining forces acting on the experiment is ejecting the testing platform on a fully stabilised Free Falling Unit (FFU), but the costs and complexity of such systems can pose a significant barrier to entry. Attitude Control Systems (ACS) which are currently available are slow-acting and tend to have a significant price tag, which reduces their effectiveness on sounding rockets and places them out of the range of low-budget projects, such as student experiments.

The aim of the ASTER project [1][2] is to demonstrate the functionality of a high-performance, low cost and easy to integrate ACS platform for FFUs. This platform shall be capable of stabilising and performing rotation manoeuvres in FFU in a reduced gravity environment using three reaction wheels. This solution will be tested with a sounding rocket launch in which a FFU is ejected and subsequently performs slewing manoeuvres.

The primary objectives of the experiment are:

1. Develop an attitude controlled FFU to be ejected from a sounding rocket.
2. Demonstrate that the ACS is capable of stabilising the FFU.
3. Recover the system after the experiment has been concluded and the FFU has landed.

Additionally, the following secondary objectives have been defined:

4. Demonstrate that the ACS can perform slewing manoeuvres of the FFU with the desired accuracy.
5. Design an FFU which is able to accommodate payloads of future experiments.
6. Design and build an FFU, including the ACS, that is easy to integrate with future experiments.

The mission timeline can be divided into six stages, which can be seen in Figure 1. [1]:

1. Launch and flight prior to ejection.
2. Ejection of the FFU before apogee of the REXUS rocket.
3. Stabilisation of the ejected FFU using reaction wheels in reduced gravity.
4. Slewing manoeuvres of the ejected FFU using reaction wheels.
5. Parachute deployment and location transmission.
6. Recovery of the FFU.

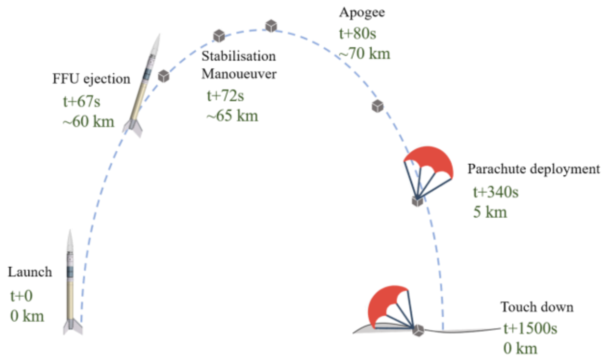

Figure 1. Timeline and altitudes of the ASTER mission stages

2. Platform Description

2.1. Project ASTER/definition

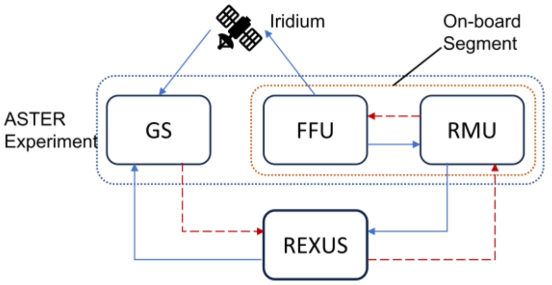

Figure 2. Overview of ASTER functional blocks and communication concept. The red dashed communication links become unavailable following radio silence.

Figure 2 shows the functional blocks which make up the ASTER experiment during the campaign. The ASTER experiment can be divided into a Ground Station (GS) and an On-board segment, as shown in Figure 2. The On-board segment can be further subdivided into the FFU and the Rocket Mounted Units (RMU). Prior to launch the GS can send telecommands to the RMU via the REXUS communication system, however this connection is lost after entering Radio-Silence Mode. Until ejection the telemetry is transmitted via the REXUS system, and following ejection the telemetry from the FFU is transmitted via Iridium. The GS is responsible for parsing and storing the telemetry and providing the capabilities to send telecommands.

The FFU is separated into several subsystems and consists of a 150mm cube with an additional 30mm high recovery module. These subsystems are the On-Board Datahadling (OBDH), the ACS, Electronic Power System (EPS), and Recovery and Communication system.The most important subsystem for the purposes of the ASTER experiment is the ACS, which consists of 3 reaction wheels (RW), the design of which is shown in Figure 3. The attitude of the FFU is determined by two IMUs. The RW components are 3D printed and CNC milled which ensures to be feasible for students. During free-fall, RWs will spin to stabilise the FFU and then a second mode will be activated, in which a series of pre-programmed slew manoeuvres will be executed. Additionally the recovery and communication system is vital to ensure a safe landing and recovery of the experiment. The recovery system will trigger the parachute release that slows down the FFU. The location of the FFU during descent is determined using GNSS data, which, along with the ADCS data, is then transmitted to the GS. RECCO reflectors will be mounted to the FFU to allow for a precise localisation after touchdown.

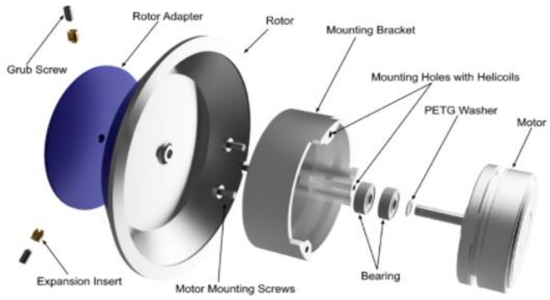

Figure 3. Reaction Wheel exploded view

The RMU houses the FFU and the ejection mechanism. It provides the electrical and communication interface between the rocket and the FFU. The RMU is responsible for ejecting the FFU from the rocket by a spring-loaded mechanism.

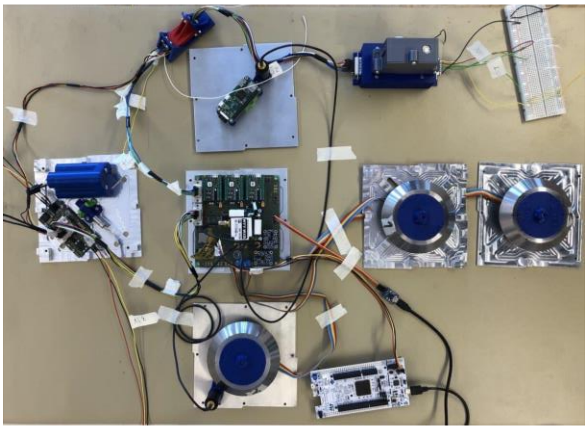

Figure 4. Flatsat configuration of the ASTER FFU during testing, Spring 2021

3. Lessons learned

Team ASTER has progressed through the regular stages of a space project design process, but has also faced additional challenges in the past few years. The team has adapted to the different situations quite well, however there were some aspects that the team could have addressed differently and might be useful for other student projects. The main lessons learned are listed in this section, and they follow the stages in the project timeline, see Figure 5, and are listed sequentially according to the order they happened.

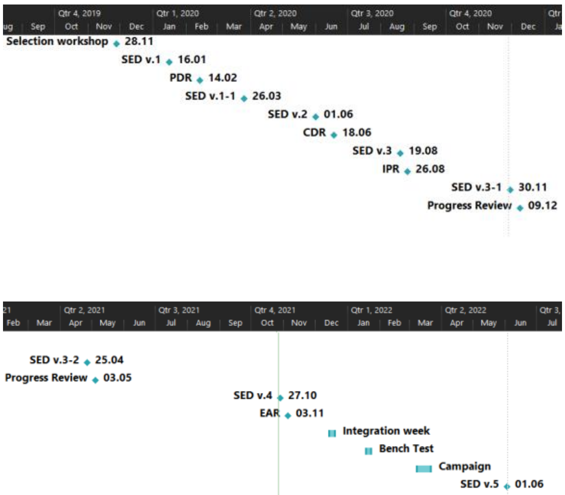

Figure 5. Project Timeline with the major design milestones indicated

3.1. *Early stages*

The main challenge during the early stages of the project was defining the experiment. The general idea was clear in the proposal, but some subsystems needed further details. The initial team was expanded through the recruitment of additional students. The larger manpower pool ensured that the team for each subsystem had the required resources. The only issue was how to manage and structure such a big team, which led to not having effective work packages and the roles of team members being ill defined. In retrospect it has become clear that it is more efficient in the long term to spend time at the beginning of a project to structure the team properly rather than starting to work without a clear aim or structure. The management of available work hours is difficult in a student team, as the members will have assignments and exams. In the early phases of the project it was especially difficult to balance the needs of member's studies and the needs of the project. However, the experiment concept was very promising and the motivation of everyone in the team pushed the project forward.

3.2. *Preliminary Design Review*

The lead up to the submission of the first version of our Student Experiment Document (SED) for Preliminary Design Review (PDR) to the REXUS panel was an intense, nerve wracking and stressful period. This is when the consequences of a lack of clearly defined roles and tasks became evident. Due to a lack of experience in this kind of project it was difficult to establish clear communication between team members which in term led to difficulties when resolving design decisions affecting multiple subsystems. However, several problems arose on the management side of the project, which negatively impacted the team.
A significant source of individual stress arose as a result of unclear guidance and instructions in the REXUS/BEXUS User-manual. This was rectified by increasing the volume of communication between REXUS personnel and ASTER following the PDR workshop week, but a big lesson learned was to get involved and communicate more before the SED-PDR report was submitted. Following PDR it was decided to modify the team structure to attempt to resolve some of the structural problems identified during the lead-up to PDR, and during the PDR itself. As such the position of Project Controller was established to help track deadlines and work within the team. It was hoped this would clarify the tasks of each team member, and lead to improved work packages.

3.3. *Critical Design Review*

The preparation of the Critical Design Review (CDR) put a lot of pressure on the team since the experiment design cannot be changed after the review. Most of the design actions that the team got at PDR were addressed, but there were others that were not fulfilled by CDR. For example, not being specific enough in some of the requirements, not providing enough details on risks and testing, and a lack of local outreach, such as radio or newspapers. The main driver of this last one was that the team members were focused on the technical aspects and it was difficult to find the time for other tasks, despite outreach being an important aspect of the REXUS/BEXUS programme. The solution the team adopted was to create an official outreach department and some of the team members could spend some of their time on outreach tasks, while continuing to work also on the technical side of the project. A short time before CDR it became clear that the changes to the team structure, implemented following PDR, would likely not resolve problems in the team culture, so it was decided that a new project manager and system engineer would provide a clean slate.

3.4. Integration Progress Review

Integration Progress Review (IPR) took place relatively close to CDR, and followed the summer holidays. As such not much progress had been made in the design or manufacture of the experiment. However, as the procurement process took considerably longer than expected, some important lessons were learnt regarding the time required for the delivery and assembly of components.

3.5. Experiment Acceptance Review

For the EAR campaign, the main focus was to have the subsystem tests carried out together with the integrated system to demonstrate a fully working system for the panel. The tests for each subsystem were pretty much done, but the integration test of the full system had not been working out properly. This was due to the fact a quantity of people had left Kiruna, and the remaining part was not able to fulfil all the various tests. Because of this, the tests inside the tracking department (GPS/Iridium), the ACS, and FFU integration into RMU were experiencing issues which could not be solved in time. Although not passing the EAR, a second chance to display the experiment functioning for the bench test and integration week were agreed upon between the panel and team ASTER.

3.6. Bench test and integration week

During the Bench test and integration week, the experiment was not able to verify a reliable communication to and from the experiment, which in term might have been induced by the STM processor and unreliable pogo pin interface. The STM was an occurring problem which was something the team didn't manage to solve. Overall, hardware issues piled up and the decision was made to fly with deactivated payload. To allocate more time for testing of the system was critical for a success in the hardware category and a closer look into redesign should have been carried out in earlier stages, mainly on the pogo pins and STM in combination with communication modules.

3.7. Covid-19 pandemic

During the beginning of the Covid-19 pandemic in 2020, various challenges presented themselves in the team. The campaign was delayed from March 2021 to March 2022 because of the epidemic, due to the risk in travelling during this time. A significant issue was the various countries each team had people located in outside of Sweden. Early summer of 2020 was the main time for team ASTER to order components, since it was positioned after the CDR, during this time some of the components were delayed and could show up months later due to the uncertainty in delivering services. During this time, team meetings were occurring every week, which could be questioned because of the standstill in the project timeline and lack of updates concerning the whole team at times. It can be argued that it might have been better to have more subsystem/department meetings and less frequent team meetings.

4. Discussions and Conclusions

Due to the challenges faced by the project in the last phase of its development, the designed ADCS system would not be able to fly as an active payload on the REXUS rocket during the scheduled 2022 campaign. But because of the uncertain geopolitical situation, the scheduled launch campaign was postponed until March 2023. This led to an opportunity to complete the set-out goals mentioned in the introduction section, Primary and Secondary objectives.

The team is currently preparing for the next Experiment Acceptance Review (EAR) that would ensure that the experiment is ready for flight. No further modifications to the experiment are allowed after EAR and therefore the team has to ensure that the technical problems are solved before the review. The team will recruit new students at the Kiruna Space Campus to have the sufficient manpower to optimise the ACS system design and perform the necessary testing at subsystem and system level on site.

Following the launch campaign at the Esrange Space Centre in Kiruna, Sweden, the post-flight analysis, and results will be gathered by the team to ultimately validate the platform. The design and results obtained will be published on an open source basis available for future experiments and missions.

ASTER is looking forward to helping students and low budget experiments access to space.

Acknowledgements

We would like to thank our supervising professor, Prof. Thomas Khun, LTU Department of Computer Science, Electrical and Space Engineering

We would also like to thank Olle Persson, LTU Department of Computer Science, Electrical and Space Engineering, for his continued guidance and support throughout this project.

This project was carried out as part of the REXUS/BEXUS programme (https://rexusbexus.net/). The REXUS/BEXUS programme is realised under a bilateral Agency Agreement between the German Aerospace Center (DLR) and the Swedish National Space Agency (SNSA). The Swedish share of the payload has been made available to students from other European countries through the collaboration with the European Space Agency (ESA). Experts from DLR, SSC, ZARM and ESA provide technical support to the student teams throughout the project. EuroLaunch, the cooperation between the Esrange Space Center of SSC and the Mobile Rocket Base (MORABA) of DLR, is responsible for the campaign management and operations of the launch vehicles.

References

[1] ASTER Website: https://aster-rexus.com/, last visited: 20th Mars 2022.

[2] F Pérez Cámara, N Janes, J Lange, Project ASTER: True Microgravity during Free-Fall with Attitude Stabilisation, *34th Small Satellite Conference*, 10 pages, 2020