THE STERN PROJECT – HANDS ON ROCKETS SCIENCE FOR UNIVERSITY STUDENT

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ABSTRACT

In April 2012, the German Aerospace Center DLR initiated a sponsorship program for university students to develop, build and launch their own rockets over a period of three years. The program designation STERN was abbreviated from the German “STudentische Experimental-RaketeN”, which translates to Student-Experimental-Rockets.

The primary goal of the STERN program is to inspire students in the subject of space transportation through hands-on activities within a project structure, to motivate universities to supervise and support the student projects with the help of financial support and to increase the lecture activities in the field of launcher and propulsion systems. The STERN program incorporates a space mission project life cycle, including preliminary, critical, integration and acceptance reviews, a thorough integration and testing campaign, launch and follow up activities.

The program is funded by the German Federal Ministry of Economics and Technology (BMWi) and managed through the DLR Space Administration.

The first STERN cycle is now almost finished. During the first cycle more than 460 students (status: February 2016) have been involved in the program. Furthermore eight rockets have been launched during three campaigns. The paper presents an overview of its hands-on activities, highlights technical results and the operational improvements over the years.

INTRODUCTION

This document provides an overview about the first STERN cycle and the three launch campaigns at ESRANGE near Kiruna Sweden. The following section introduces the STERN program, the used rockets with their hybrid and solid rocket motors as well as the operational activities during the campaign.

STERN PROGRAM

The aim of the STERN program is to inspire students in the subject of space transportation through hands-on activities, and to motivate universities to supervise and to give financial, infrastructure and laboratory support and to increase the lecture activities in the field of launcher and propulsion systems. This will ensure the availability of highly educated professionals in launcher systems for the future also taking into account Germany`s crucial part in the Ariane program.

In April 2012, the German Aerospace Center DLR launched the STERN program, which is supported by funds from the German Federal Ministry of Economics and Technology (BMWi) and conducted by the DLR Space Administration. Three DLR institutions at Oberpfaffenhofen, Lampoldshausen and Trauen, together with the space administration, supervise work and launch campaigns and hold reviews and conducting workshops.

Figure 1: Logo of STERN

The program is open for all German universities which offer aerospace engineering lectures and offer students the possibility to develop, build, test and launch their own rockets in university teams. The focus is on the development of the complete vehicle system within three years.

The student’s should develop their knowledge in the following disciplines:

- Rocket propulsion and testing
- Aerodynamics,

- Flight dynamics (e.g. flight stability, loads, trajectory calculation and optimization, etc.)
- Mechanics and lightweight structures
- Telemetry, data acquisition
- Testing of the rocket and its subsystems
- Application of professional tools (e.g. CAD, CFD, FEM)
- Project Planning and organization (time, budget, technical risks, etc.)
- Launch preparation and operation
- Soft skills (different disciplines and customers)

From the beginning of the project until the launch of the rocket, the students have to conduct several reviews in which they will have to present the current status of their work to a review team consisting of DLR Space Administration, DLR experts from Mobile Rocket Base (MORABA) and the DLR Institute of Space Propulsion, but also further external experts if required. This aims to increase the chance of achieving the mission goal of the student teams and improve safety during development and launch of the vehicle. At Lampoldshausen the M11.5 Student Test Field has been set up and it is available for performing motor test campaigns under the supervision of engineers and scientists.

The requirements for participation in the STERN program are

1. Formal requirements
   - German universities focusing on aerospace, particularly on launcher aspects. Teaching content at the university must be linked to the project.
   - Conduct of reviews including the participation of a minimum of one reviewer from DLR MORABA, DLR Institute of Space Propulsion and the DLR Space Administration, respectively
2. Technical requirements
   - The rocket shall reach a minimum apogee of 3 km and reach a supersonic velocity
   - The rocket shall have recovery system, and
   - The rocket shall have a telemetry unit to transmit the most important trajectory data (acceleration, velocity, altitude and GPS-position) during its trajectory.

2.1 Overview of the student rockets

Eight teams are participating in the STERN I program. Five of them launched their rockets in the last two years. Due to the expected flight altitude, the launches took place at the SSC ESRANGE Space Center in Kiruna, Sweden. An overview of the rockets is given in the following:

TU Berlin, DECAN

"DECAN – Deutsche CanSat-Höhenrakete" is the designation of the two-stage sounding rocket project of the Technical University of Berlin. However it was decided to launch only the Engineering and Qualification Model (EQM) and Flight Model (FM) of the upper stage at ESRANGE. Both rockets were identical except that one contained a telemetry payload and the other one a dummy payload. The predicted apogee of the DECAN "SHARK" rockets was 6.5 km. ("SHARK" is the name of the rocket) The solid rocket motor is a commercially available class N motor for high power rocketry with level 3 certification. Its propellant is an aluminum / ammonium perchlorate composite (AL + APCP). The project was performed under professional supervision based on ECSS standards and was supported by the Aerospace Institute of the Technical University of Berlin. Detailed information about the development of the rocket and the motor is given in reference [1].

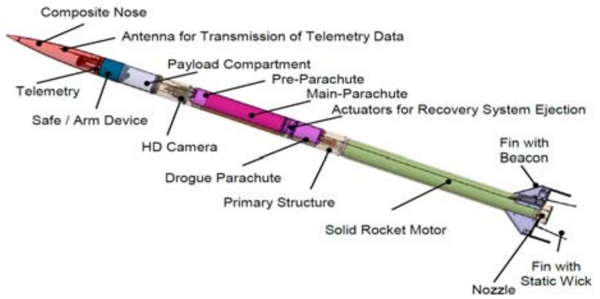

Figure 2: System of the SHARK rocket

DECAN SHARK I was launched from the Medium Range Launcher (MRL) at 13:55UTC on October 27, 2015 and DECAN SHARK II was also launched from the MRL at 08:55UTC on October 29, 2015. For safety reasons a launch elevation of 80° was set by the launcher. If the elevation angle is an acute angle the rocket leaves the launch side faster as with a rectangular elevation angle. Before lift-off of SHARK I, an unexpected long ignition delay of approximately 8 seconds of the rocket motor was observed. The reason for this was the low temperature of the rocket motor resulting from the low ambient temperature during the extended countdown. The gas generator inside the combustion chamber needed more time to generate the required hot gas in order to provide the ignition temperature for the propellant grain. After the ignition of the solid motor, the rocket left the launcher and a stable flight trajectory was observed. It can be assumed that the integrity of the rocket structure was ensured during the entire flight. Furthermore, telemetry data was received during the flight and a maximum altitude of 5,556 m was reported. Moreover, a maximum velocity of 401 m/s (Mach 1.2) was measured by the sensors of the telemetry system. The triggering of the drogue parachute was confirmed by the telemetry system. However, the recovery system malfunctioned. It was observed that the rocket descended without any parachute and crashed into the ground.

The DECAN SHARK II rocket had a stable flight trajectory as well and reached an altitude of 5,703 m. A maximum velocity of 414 m/s (Mach 1.2) and an acceleration of 103 m/s^2 (10 g) were measured. The triggering of the drogue and main parachute was reported from the telemetry system. It was observed that the drogue parachute was ejected; however the main parachute malfunctioned. Thus, the vehicle crashed into the ground as well. [2]

TU Braunschweig, ERIG:

The ERIG is an association at the Technische Universität Braunschweig. As an in the STERN participating team, the ERIG is developing a research hybrid rocket and a new hybrid rocket engine. The rocket named Faust was powered by a hybrid rocket motor called HYDRA3X. The HYDRA3X engine consists of a solid HTPB (Hydroxyl-terminated polybutadiene) / aluminium powder mixture and liquid oxidizer (nitrous oxide) and was planned to deliver 1.25 kN of thrust, which should allow the rocket to reach altitudes in the order of about 5 km. The rocket FAUST was used with external helium pressurization. Furthermore, ERIG was designing a telemetry platform containing of an inertial measurement unit (IMU) and navigation data via GPS, as well as a new proprietary flight simulation tool called ExRaS (ExperimentalRaumfahrt-Simulation). This allows an individual simulation run with different configurations and the estimation of key parameters such as the maximum altitude and velocity. By including online wind data, it is possible to perform a complete flight simulation and thus predict where the vehicle will impact.

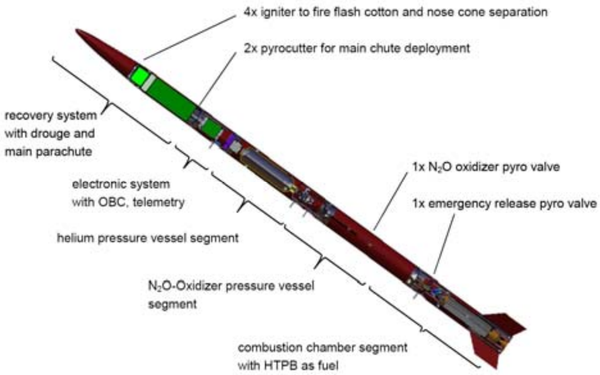

Figure 3: System of the FAUST rocket

Detailed information about the development of the rocket and the motor is given in reference [3].

FAUST was launched from the team´s own launcher at 08:45UTC on October 22, 2015 (see Figure 4) with an elevation of 80°. The launch went well but the recovery system did not work as expected. According to the flight data analysis it is assumed that the drogue chute deployed as planned, but the high velocity of 100 m/s due to the launch angle caused higher aerodynamic loads than expected. Even the integrated damper was not able to alleviate this and the drogue chute ripped off and was unable to pull out the main chute. This theory is supported by the recovered parts. The main chute was found inside the rocket while the drogue chute was missing. Later analysis and pull tests show that the rod between the rocket and drogue chute was weakened by knots. In conclusion the failure was caused by several reasons. A lower than planned launch angle inducing higher loads, a weakened rope by knots and furthermore, a wrong load calculation.

Nevertheless, the propulsion system and the electronics performed as planned. No anomalies were detected during launch sequence and flight. However, due to the harsh impact, no flight data could be recovered from the on board memory. Only data transmitted during flight was available. [2], [3]

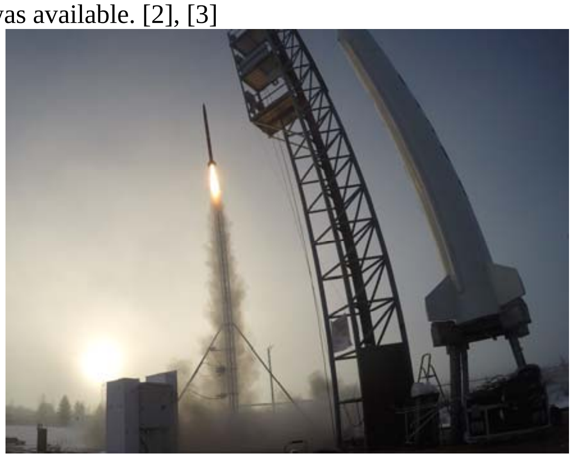

Figure 4: Launch of FAUST

HS Bremen, AQUASONIC

The project AQUASONIC, aimed to develop a two-stage sounding rocket transporting a 2 kg payload to a ceiling altitude of 6 km while reaching a velocity of at least Mach 1. Concept, design and realization of the optimized, lightweight rocket system was performed by graduate and undergraduate Aerospace and Aviation students of Bremen City University of Applied Sciences, during their final phase of studies. The hybrid propulsion system is based on Polyethylene as fuel and Nitrous Oxide as oxidizer. The engine was pressure-fed using a regulated Helium pressurization system. Moreover a two-stage parachute based recovery system was foreseen. Recovery parachute ejection was initiated by the on-board computer, based on barometric altitude, acceleration and rocket attitude. A redundant activation system with independent sensors, microcontroller, telemetry link and power supply was also foreseen. Detailed information on the rocket is given in reference [5]

The launch campaign at Esrange took place from April 4, 2016 until April 14, 2016. Everything went according to the schedule, until the first launch attempt on April 8, 2016. Due to a technical problem, the AQUASONIC rocket had a misfire and did not leave the launcher. Conclusion of detailed analysis was that the ignition material (rocket-candy) was not kept at the desired place inside the engine. Intensive testing including reproduction of the failure, lead to the decision to use an additional holding plate made of PLA, which would have a minor impact on the flow field in the rocket motor because it would burn completely away during motor operation. Additionally, the time delay between ignition of the rocket candy and activation of the pyro valve was reduced to create a longer overlap time between igniter operation and oxidizer flow.

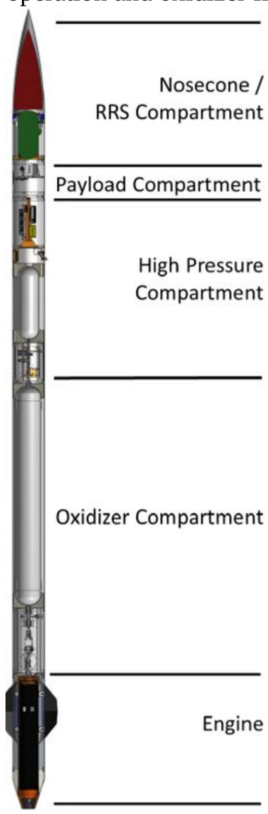

Figure 5: System of the AQUASONIC rocket

The second launch attempt was set for April 14th. The rocket was launched at 04:00 UTC with a launcher elevation of 80°. Around nine seconds after lift-off, no telemetry data was received, because the link margin decreased below its minimum required threshold. According to Mission Analysis, the rocket should have reached an apogee of about 6,5 km after 40 s of flight. The malfunction of the primary telemetry system resulted in a lack of information about flight performance and the function of the recovery system. After extrapolating the trajectory the rocket was found on July 16, 2016. The on-board data was destroyed by the harsh impact of the rocket. [4], [5]

U Bremen/ ZARM, ZEpHyR

The ZARM Experimental Hybrid Rocket, ZEpHyR for short, which is a contribution of the University of Bremen, was powered by a hybrid rocket motor. The engine utilised paraffin as a fuel and liquid oxygen as an oxidiser, which was produced by their own liquefier. The pressurant was Helium. The engine is designed to develop 1,8kN of thrust for thirty seconds, resulting in a total impulse of about 54kNs. The recovery system included a two stage parachute system. Moreover the telemetry system, which is part of the rocket payload, features OBC, GPS, IMU and pyro-modules. Detailed information on the rocket is given in reference [6].

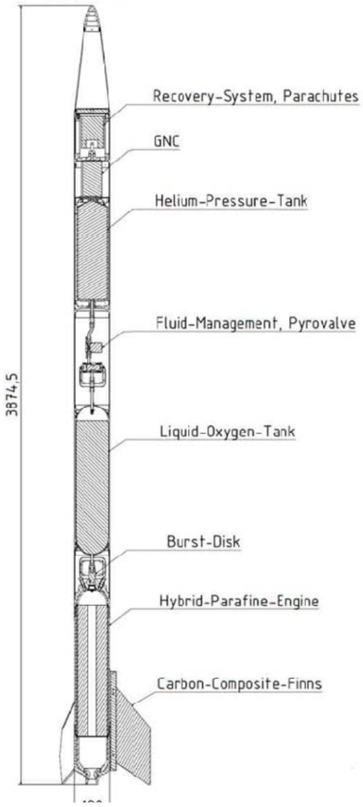

Figure 6: System of the ZEpHyR rocket

ZEpHyR was launched from the MANII launcher at 08:57UTC on April 16, 2016 and was the first paraffin/LOX hybrid sounding rocket to be launched in Europe (to the knowledge of the authors). Due to the low acceleration during lift off, the launch elevation was set to 75° by Esrange.

A first analysis of the flight indicates that the burning time of the engine was lower than predicted, resulting in a significantly reduced performance of the vehicle. A malfunction of the Functional Propulsion System could be excluded shortly after the flight. Video and telemetry data show clearly nominal engine behaviour. Most likely the oxidizer tank was not filled with enough liquid oxygen during the fuelling process. Due to technical complexity, a rising pipe inside the LOX-tank was used to check the filling level instead of cryogenic sensors or a scale. Filling operation is completed as soon as drops of LOX are visible and there is no significant vapour of gaseous oxygen at the outlet of the rising pipe. The latter was monitored by a camera to observe the filling process from the control room. On the launch day, the sky was clouded with a light snow fall and the camera pointed against this white background, make it difficult to see vapour or drops and resulted in a lower fuelling level.

As with previous flights a malfunction of the recovery system occurred. The recovered debris of the rocket indicates that the drogue parachute was deployed but was unable to handle the forces during deployment. The wreckage indicates that the main line connecting the drogue to the rocket ruptured, leading to non-deployment of the main chute and loss of the vehicle. This coincides also with telemetry data. Due to the hard impact of the rocket the storage card with high sampling data rates was damaged and only the telemetry data with 1Hz and the video material from the outside cameras are available. [4], [6]

U Stuttgart, HyEnD

The student team Hybrid Engine Development (HyEnD) of the University of Stuttgart has developed a hybrid rocket called HEROS (Hybrid Experimental Rocket Stuttgart) with a design thrust of 10 kN, a total impulse of over 100 kNs and a lift off mass of up to 175 kg. The major subsystems are the rocket engine, propellant management, telemetry unit, a recovery system and ground support equipment. During flight the telemetry unit sends trajectory data to the ground station. Additionally a flight computer stores telemetry data, tank pressure and combustion chamber pressure to a disk. The flight computer also triggers the recovery system, which consists of a braking parachute, which is ejected at apogee, and a main parachute, which is deployed at a fixed altitude. After the successful and safe landing of the rocket, HEROS is tracked with last GPS data and a radio transmitter. HEROS is reusable to a high degree.

HEROS has been launched in the DLR educational program STERN the first time at 14:45UTC on October 22, 2015 from the MRL launcher. However combustion instabilities occurred during lift-off, due to low oxidizer temperature. This led to a failure of the combustion chamber in the flight after ~7s and the rocket did not reach the targeted altitude. The propulsion system uses a paraffin-based solid fuel and Nitrous Oxide (N_2O) as the liquid oxidizer. The launch has been analysed in detail and a Failure Analysis Review was performed in order to find the root cause of the malfunction. It could be shown, that these instabilities appeared also in ground tests, when the N_2O temperature and corresponding vapour pressure was not high enough to maintain an adequate differential pressure over the injector.

An extension of the project for a 2nd campaign was granted by the DLR Space Administration, with a launch in October, 2016. Small improvements in the rocket design were made for another launch including an improved heating system and increased number of sensors.

HEROS 2 was launched on October 31, 2016 at 1200UTC. During the launch, a failure occurred in the on-board electronics. Everything worked nominally during the countdown, the electronics worked nominally until launch. Exactly at T-0, the telemetry was lost completely. It was not possible to regain reception. Since both units failed simultaneously at T-0, when mechanical loads are small, a failure due to mechanical reasons is highly unlikely, so the failure was presumably caused by an electrical issue. In an array of tests, it was shown that an electromagnetic interference from the firing line induced a voltage in the on-board computer connection line and thereby a shut-off command for the computer. All improvements were implemented before the launch of HEROS 3. The third rocket was launched on November 8, 2016 at 0930UTC. HEROS 3 was very successful. The maximum flight altitude was 32300 m. This sets a new record for European student and amateur rocketry. The maximum velocity of HEROS 3 was 2600 km/h with a Mach number of 2.3. The parachute system deployed at apogee and the rocket landed softly without any damage in 20 km distance to the launch pad.

The other student teams are described shortly below:

- SMART (TU Dresden): Single stage, liquid propellant using ethanol and liquid oxygen (LOX), fed by pressurized nitrogen (N_2). Engine tests with increased thrust from 500 to 700N in 2017.
- HyComet (FH Augsburg): single stage rocket, lift-off mass 25 kg, hybrid motor (polyethylene (PE) + liquid oxidizer (nitrous oxide (N_2O), flight altitude 3-5 km, planned launch: 2017
- Hyper (TU München): Single staged rocket, hybrid: cryogenic propellant using liquid oxygen (LOX) and hydroxyl-terminated polybutadiene (HTPB), flight apogee 15km, battle ship engine test: 2017

2.2 Overview of the campaigns

Three Campaigns were conducted during STERN I-October 2015, April 2016 and October 2016-. All launches took place at the SSC ESRANGE Space Center in Kiruna, Sweden. Five student groups (Technical University of Berlin, University of Applied Sciences of Bremen, Technical University of Braunschweig, University of Stuttgart, and ZARM/ University Bremen) could successfully launch their rockets under supervision of DLR scientists and engineers.

Three of the university teams (TU Braunschweig, U Stuttgart and TU Berlin) attended the launch campaign in October 2015, with four rockets in total. All rockets, i.e. two hybrid rockets and two identical solid rockets, could be launched within the scheduled two weeks campaign.

The second STERN campaign was from 03.04 till 15.04.2016 with two rocket launches. HS Bremen and ZARM University Bremen launched their hybrid rockets.

Up to now the last STERN campaign was from 24.10 till 09.11.2016. The University of Stuttgart launched two rockets. The second flight had an apogee of more than 32 km and is the European record for student rockets.

For the launch preparation and operations phase, the responsibility for each mission resided with the STERN teams. MORABA coordinated and managed the mission activities at the launch site.

3. Lessons Learned

All an all, there are points which could be better performed in the next project but making mistakes is the best way of learning. The following lessons learned is done by MORABA to determine and analyse elements of the project that were successful or unsuccessful. The list is applicable for all different project organizations (DLR Space Administration, DLR Institute of Space Propulsion, University, SSC and DLR MORABA).

3.1 Organizational

Points regarding project management, which should be improved in future projects or which were positive and should be done again in future projects:

- Regular project meetings and splinter meetings between the different project organizations
- Requirements should always be achievable within the scope of the project. If they are not, then this can lead to unnecessary diversions of resources which in turn may compromise progress.
- Fileserver that is easy to operate and accessible for all project members
- English language during meetings and for documentation
- All different project organizations should visit the students at their test facility

3.2 Technical

The following subchapters should give an overview on the main technical lessons learned of STERN program. These lessons learned, should help future teams to design, build and fly their rockets.

General

- Try to use components that could be replaced. The design of the system should be constructed that parts could be replaced. The complicated part on having spare parts is the balance from cost and need. A campaign could be over without a spare part but which one do you need during a campaign.
- Try to use components that come with a datasheet and/or a manual including all necessary information
- Where possible, design should attempt to include COTS components to reduce lead times in manufacturing. It can also be prudent to simplify designs such that the students themselves can fabricate many of the parts. This will reduce mechanical workshop costs and lead-times.
- Accurate vibration tests are absolutely essential to ensuring the payload will function correctly on the launch day
- In case of a harsh rocket impact, it is recommended using a black box to protect the rocket flight data.

Propulsion

- All further STERN rocket motors will be full scale tested
- Do intensive testing under representative conditions (e.g. temperature)
- The engines (or even the entire propulsion subsystem) should be tested in (almost) vertical position. At least a vertical ignition test shall be performed.

Communication

- External standalone system to localise the rocket (for example an Iridium system from SSC)
- Use an independent “beacon” for location of the rocket
- Do intensive testing under representative conditions (e.g. modems inside rocket)

Recovery System

- Recovery system is electrically independent of the communication system
- Intensive testing under almost realistic conditions
- More education about recovery system, selection, construction, handling/ packing of a parachute
- Recovery system should be improved for high horizontal velocities during apogee.

Operation/ campaign

- A communication solution between blockhouse and launcher → for example headset solution
- More spare parts at the range:
  - gas bottles connections
- Grounding concept should be discussed in advance with SSC and MORABA experts
- Working hours needs to be shorter for students during a campaign
- Handling of pyrotechnics: Always one person from

SSC should be supervising the students

- The duration planning of a STERN Campaign should be increased because of weather, daylight- or other technical issues.

4. Conclusion & Outlook

The experience and results from the STERN campaigns demonstrated a very good performance of the student rockets and the good approach for student support by the STERN program strategy. The challenging and extensive task of the preparation and conduction of a launch campaign is an excellent opportunity for a large gain of hands-on experience for the students.

The STERN program supports the universities in the education of the students by the intense knowledge gain in designing, building and testing of rockets in the scope of ambitious projects. A second funding period (STERN II) will start within 2017 currently planned with four universities.

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