The educational programmes with involvement of DLR´S Mobile Rocket Base

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***Abstract*—Mobile Rocket Base (MORABA), a department of German Aerospace Center's Space Operations and Astronaut Training provides the national and international scientific community with opportunities to prepare and implement rocket- and balloon-borne experiments. The fields of research include aeronomy, astronomy, geophysics, material science and hypersonic research. Further, MORABA supports educational programs for scientific experimentation as well as engineering disciplines. This paper presents MORABA's involvement in the educational programs "STudentische Experimental-RaketeN", or STERN shortly, and REXUS / BEXUS. On one side, STERN supports students from aerospace universities across Germany to design, build, test and launch their self-developed rockets. On the other side, the REXUS/BEXUS programme allows European students to carry out scientific and technological experiments on research rockets and balloons. We discuss the different technical views and outputs of the MORABA activities within these programmes. In conclusion, the range of different topics makes the programmes very effective and enhances various skills of the participating students, partners including MORABA.**

Keywords— STERN, REXUS, BEXUS, sounding, balloon

I. Introduction

It is strategically as well as economically important for Europe to secure its access to space through launch vehicles or scientific payloads of its own. To make sure that Europe will continue playing a crucial part in the development of e.g. new launcher systems and to prevent any loss of development competence, students and young professionals have to be trained and educated [5]. Especially in Europe, we are missing hands on space education [5]. The goal of space related educational programs is to increase awareness to the needs which the space sector faces now and in the future [5]. MORABA is taking a prominent role in the effort to inspire interest in science, technology, engineering and mathematics through its unique mission, workforce, facilities, research, and innovations. The paper gives an overview about MORABA and its actives inside the educational programs with MORABA participating.

II. Mobile Rocket Base (MORABA)

The Mobile Rocket Base (MORABA) was founded in 1966 as part of the Max Planck Society (Arbeitsgruppe für Weltraumforschung) under the initiative of Professor Dr. Reimar Lüst, at that time founding director of the Max Planck Institute for Extra-terrestrial Physics. MORABA was later, in 1967, integrated into DLR and is based in Oberpfaffenhofen, Germany.

MORABA's main task is to support the national and international research community in the preparation and execution of sounding rocket- and balloon-borne experiments. These cover a variety of scientific fields, such as atmospheric physics, astronomy, microgravity and linear acceleration experiments, hypersonic research, technology testing and of course education. By providing and operating mobile infrastructure (TT&C, RADAR and rocket launchers), it is possible to perform complex scientific missions at almost any location that might be required by the experiment. Most frequently, launches are conducted from Esrange Space Center (Sweden), Andøya Space Center (ASC) and Spitzbergen (Norway), Natal and Alcântara (Brazil), but remote locations like Antarctica or Woomera (Australia) have also been used. Minimal infrastructure is required to establish a launch site at other desired locations.

The development of new launch vehicle systems to meet the scientific requirements of the various missions constitutes a key capability of MORABA. Military surplus propulsion units are converted for the use as sounding rockets and commercially available systems are acquired as necessary. The cost-effective combination of these motors to make up the desired launch vehicle as well as development of rocket subsystems like fin, motor adapter are key competences of MORABA. A long standing collaboration with our partners in Brazil (DCTA/IAE) offers a unique ability to directly tailor the design of new rocket motor systems for research purposes in a collaborative approach with the rocket motor manufacturer.

A further objective of MORABA is the development, fabrication and testing of commercially unavailable mechanical and electronical components and systems for sounding rockets and balloons as well as for short duration satellite missions.

MORABA is one of a few institutions worldwide which offers the science community all necessary infrastructure and expertise to perform sounding rocket based missions. The mobile infrastructure of MORABA meets highest international standards and enables even very demanding scientific missions. MORABA is ISO 9001 and OHSAS 18001 certified for "Preparation and Conduct of Sounding Rocket Missions for various Scientific Applications" by TÜV Süd. Primary customers of MORABA's expertise and facilities are universities and research institutions, DLR institutes, as well as national and international organizations and industry. The majority of the projects with MORABA participation are programmatically funded by the German Federal Ministry of Economics and Technology (BMWi), the DLR Space Administration and ESA.

III. SPACE EDUCATION

The aim of the space educational programs are to help young Europeans to gain and maintain an interest in science and technology, with the long-term objectives of contributing towards the creation of a knowledge-based society and ensuring the existence of a qualified workforce that will ensure Europe's continued leadership in space activities [4].

Nowadays, worldwide it exist numerous educational space programs. MORABA participates into two educational hands-on projects:

- REXUS BEXUS program
- STERN program

A. REXUS BEXUS

Each year the German-Swedish program "REXUS BEXUS" (Rocket/Balloon Experiments for University Students) supports up to 20 student teams from across Europe to participate in a hands-on educational program allowing them to fly their research or technology demonstrating experiment on one of two sounding rockets or two stratospheric balloons. An important feature of the program is that the students experience a full project life-cycle which is typically not a part of their university education and which helps to prepare them for further scientific work. They have to plan, organize, and control their project in order to develop and build up an experiment but must also work on the scientific aspects. The program logo is shown in Fig. 1.

Fig. 1: REXUS BEXUS logo

The REXUS/BEXUS programme is realised under a bilateral Agency Agreement between the German Aerospace Center (DLR) and the Swedish National Space Board (SNSB). The Swedish share of the payload has been made available to students from other European countries through a collaboration with the European Space Agency (ESA). EuroLaunch, a 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. Experts from DLR, SSC, ZARM and ESA provide technical support to the student teams throughout the project. REXUS and BEXUS are launched from SSC, Esrange Space Center in northern Sweden. The REXUS BEXUS program has been carried out in its current format since over 10 years. In that time, it has developed significantly, building upon strengths to provide a richer experience and increasing the educational, scientific, and promotional outputs [6].

BEXUS experiments are lifted by a balloon with a volume of 12 000 m³ to an altitude of 25-30 km, depending on total experiment mass. The total mass may be more than 300 kg and the flight train length more than 100 m. A typical BEXUS flight configuration consists of a balloon of the Zodiac 12 SF type which is filled with Helium. Payloads are assembled on a medium-sized gondola (1.16 m x 1.16 m x 0.84 m). The flight duration is 2-5 hours. The BEXUS payload is modularized to provide simple interfaces, good flexibility and independence between experiments. Mobile Rocket Base is partly responsible for the campaign management and operations of the launch vehicles. Furthermore, MORABA provide technical support to the student teams throughout the project.

REXUS experiments are launched on an unguided, aerodynamic-stabilized rocket powered by an Improved Orion motor with solid propellant. It is capable of taking maximum 108 kg of payload to an altitude of between 75 km and 85 km. The REXUS payload is modularized to provide simple interfaces, good flexibility and independence between experiment modules. Up to five experiment modules with a 14 inch diameter and maximum payload length of 6257 mm can be accommodated. The vehicle consists of an Improved Orion motor, a motor adapter, a recovery system, a service system, the experiment modules, a nosecone adapter ring, sometimes a nosecone experiment and either an ejectable or non ejectable ogive nosecone. The REXUS rocket systems are mainly provided by MORABA and shown in Fig. 2.

1. Tailcan and Fins

Three fins on the REXUS rocket provide stability during flight and allow the rocket to maintain its longitudinal axis'

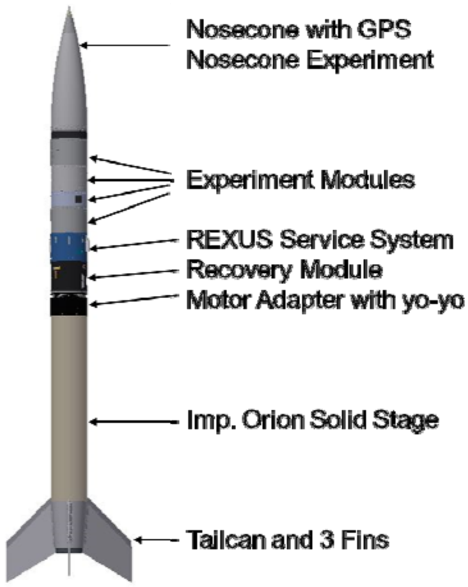

Fig. 2: REXUS rocket

orientation and intended flight path. The fins are mounted at the tailcan which is attached to the motor. Fitting fins on a rocket serves to provide lifting surfaces at the aft end of the motor and thereby position the Centre of Pressure aft of the Centre of Gravity. Moreover, the finset has a setting to spin the rocket at a defined rate as a function of flight velocity. The spin of the rocket reduces its impact dispersion. Also a retractable launch lug is mounted on the tailcan which facilitates attachment of the rocket vehicle to the launcher rail.

2. Motor Adapter incl. yo-yo Despin

The main objective of the motor adapter is unidirectional separation of the payload and the motor. The motor separation can be divided in two events.

a) Opening and jettisoning of the manacle ring

b) Motor separation by plungers

A further objective of the motor adapter is to end the spinning motion about the longitudinal axis prior to separation of the payload. A de-spin system (the yo-yo) is used to de-spin from approximately 3 Hz to a maximum residual spin rate of +/-0.08 Hz (+/-30°/s). The yoyo consists of two cables with masses at the ends. The cables are wrapped around the motor adapter and the two masses are placed diametrically opposite to each other. When the masses are released, the spin of the rocket flings them away from the spin axis and the cables are unwound. This transfers angular momentum from the rocket to the masses and thus reduces the spin of the rocket to the desired value.

3. Recovery Module

The recovery system is capable of landing payloads with the designated payload mass from approximately 100 km apogee. The system is designed to decelerate from 150 m/s sink velocity to 8 m/s impact velocity. It is a two stage parachute system. The drogue chute has a diameter of 1,36 m and the main chute of 6,90 m. The recovery module is positioned in the back end of the payload and contains a drogue chute, which deploys the main chute. It also contains a heat shield, which protects the parachutes during the high speed part of the re-entry. Barometric switches initiate the pyrotechnic sequence for ejecting the heat shield and releasing the parachutes at a present altitude and subsonic speed.

4. REXUS Service Module

The objectives of the Service Module are to establish the communication between the ground and the experiments, and to control the experiments. Furthermore it records significant flight performance parameters, like position, acceleration, speed, rates and attitude. Additionally, the Service Module has the capability to supply energy to the experiments.

The Service Module consists of two sections. The first one contains the electronic part of the Service Module (E-Box), while the other devices such as RF-parts, GPS, sensors and batteries are mounted on the bulkhead of this module.

5. Nosecone

The REXUS rocket has two different kinds of nosecone – ejectable or non ejectable. The use depends on the request of the experiment. If an experiment team needs to be placed under the nosecone and requires to eject something, an ejectable nosecone is provided. Both nosecone types are 14 inch in diameter, 4:1 ogive nosecones. The nosecone separation process is the similar to the motor separation by manacle ring and plungers. Inside each nosecone is a GPS tip antenna.

The MORABA support within the REXUS program, which is offered to the international student community, includes in cooperation with all partners the following services:

- General management and planning of the REXUS project
- Issue of the REXUS user manual and support for the other guidelines
- Organization of the Training week at DLR Oberpfaffenhofen every second year
- Review of selection proposals and selection workshop participation
- Provision of subsystems necessary for a REXUS rocket mission (see description above).
- Integration of participating experiment modules into the flight configured payload and pre-flight testing of the payload (TM, TC, flight simulation test, dynamic balancing, vibration tests and determination of physical properties).
- Transport of modules and required equipment from the integration facility to Esrange.
- Organization and planning of the launch campaign incl. issuing the flight requirements plan
- Payload assembly and testing at the range.
- Launch and recovery.
- Data acquisition with provisions of real-time, quick-look and replay data from the modules and the payload subsystems (e.g. g-levels).
- Disassembly of payload and return of experiments.
- Post flight report.

B. STERN

The program "STudentische Experimental-RaketeN", designated STERN, allows students from aerospace universities across Germany to design, build, test and launch their self-developed rockets. On behalf of the German Federal Ministry of Economics and Energy (BMWi), the DLR Space Administration conducts the German Space Program. In the frame of the national space program, STERN was initiated and launched in April 2012 [5]. The program logo is shown in Fig. 3.

The goal of the STERN program is to increase awareness to the need of the space transportation sector regarding both the technical sector and the human resources. Thus, the main objectives of the program are threefold, namely [5]:

- Inspire student interest in space transportation subjects through hands-on activities during development of their own sounding rocket,
- Entice universities with financial support to supervise and support student projects,
- Increase course work and lecture activities in fields such as launch systems, propulsion systems or similar which address space transportation issues.

Fig. 3: STERN logo

The focus of the STERN program is the development of the complete vehicle with main focus on the propulsion system within three years. Therefore a payload is not mandatory and not part of the program. According to the program announcement [5], the sounding rocket has to suffice a specific set of requirements, namely:

- Minimum velocity of Mach 1,
- Mandatory recovery system,
- Functioning telemetry system to transmit key parameters including at least – but not limited to – acceleration, velocity, altitude and position of the rocket.

Besides these basic requirements, one key characteristic of STERN is that the university teams have the freedom to design their sounding rockets as they see fit. There is no principal upper limit on the flight altitude or restrictions in the choice of propulsion concept (solid fuel, liquid fuel, hot water or hybrid), although there can be restrictions by the launch range. A commercially available solid propulsion motor can be used as well as own developments such as, for instance, solid, liquid, hybrid or hot water propulsion.

Eight teams were selected by DLR Space Administration to participate in the STERN I program with a project start in April 2012. The first STERN cycle is coming to a close at the middle of 2018. Five student teams launched a total of eight rockets in Kiruna, Sweden, during three separate campaigns. A second funding period (STERN II) started in June 2017 currently planned with three university student teams.

Fig. 4 depicts a summary of the participating STERN I universities, their sounding rockets and some system properties. There are seven single-stage rockets all based on hybrid propulsion systems. TU Dresden developed a liquid, single-stage propulsion system based on an ethanol-LOx mixture. The hybrids used either nitrous oxide or oxygen as oxidizers. Their solid fuels ranged from PE, HTPB to paraffin. TU Berlin developed a two-stage rocket. The first stage is based on hot-water propulsion, while the second stage burned a commercially available solid rocket motor. U Stuttgart built HEROS, the longest rocket measuring about 7.5 m. SHARK by TU Berlin was the shortest rocket just shy of 3 m.

As in any development program, the students have to pass several reviews in which they have to present and defend their rocket design in front of an expert panel. This practically oriented study should prepare the students for possible later work in industry. The DLR Mobile Rocket Base and the DLR Institute of Space Propulsion as well as the DLR Space Administration accompany the students during the reviews and until launch. Hereby the Space Propulsion Institute supports with its research and testing experience of rocket engines and

University	UAS Augsburg	TU Berlin	TU Brunswick	UAS Bremen	U Bremen	TU Dresden	TU Munich	U Stuttgart
Engine	1-stage: Hybrid (PE + N_2O)	2-stage: 1. Hot water, 2. Solid (Al + APCP)	1-stage: Hybrid (HTPB + N_2O)	initial 1-stage: Hot Water 2-stage: Hybrid (PE+N_2O)	1-stage: Liquid (Paraffin + LOx)	1-stage: Liquid (Ethanol + LOx)	1-stage: Hybrid (HTPB + LOx)	1-stage: Hybrid (Paraffin + N_2O)
Thrust (nominal)	1.000 N	2.000 N	1.250 N	2.350 N	1.800 N	500 N	10.000 N	10.000 N
Mass at lift off	23,4 kg	23 kg	24,1 kg	75 kg	80 kg	≤ 25 kg	150 kg	172 kg (3) - 176 kg (1)
Burning time	10 sec	6,9 sec	10 sec	16 sec	30 sec	20 sec	15 sec	25 sec
Max. acceleration	9 g	14 g	3,65 g	2,3 g	5,7 g	2,5 g	6 g	7 g

U = University, TU = Technical University, UAS = University of Applied Science

Fig. 4: STERN rocket family

MORABA with its experience in sounding rocket operations and mission and system design.

Likewise, the reviews as well as special workshops offer a platform for the exchange of technical information. In the project there are two kinds of workshops. The first one called STERNStunden, which is organized every two years, is conducted in Oberpfaffenhofen. This workshop focuses on the rocket vehicle system and all subsystems except the engine. The DLR Institute of Space Propulsion organizes every year the second kind of workshop, which is dedicated to propulsion relevant topics. Beside lectures, the major part consists of exercises, where the students have the opportunity to strengthen their practical capabilities.

The DLR Mobile Rocket Base and the DLR Institute of Space Propulsion are also responsible for the coordination and organization of the program, which means releasing the STERN user manuals and guidelines, creating templates, organization of a teamsite etc. Moreover, DLR MORABA is in charge of the social media outreach program of STERN.

During the launch campaign, the responsibility for each mission resided with the STERN teams. MORABA coordinated and managed the mission activities at the launch site. [2], [3]

IV. Conclusion

The demanding aspect of all space educational programs is that it requires knowledge in a large variety of engineering topics as well as operational processes. This range of different topics makes the REXUS BEXUS as well as the STERN program very appealing and enhances various skills of the participating students and partners. The challenging and extensive tasks of preparing and conducting an experiment or a launch campaign are excellent opportunities to gain hands-on experience for the students. However, the profit from such a project is not limited to the students. Also the space industry or DLR as a non-profit research organization derives benefits.

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