IAC-14-A2.5.7

DLR'S MOBILE ROCKET BASE – 47 YEARS OF MICROGRAVITY AND TECHNICAL EXPERIMENTS ON SUBORBITAL FLIGHTS

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Mobile Rocket Base (MORABA), a division of the Space Operations and Astronaut Training Department of DLR (Deutsches Zentrum für Luft- und Raumfahrt) provides the national and international scientific community with the opportunity to prepare and implement rocket- and balloon-borne experiments. The fields of research include aeronomy, geophysics, material science and hypersonic research and are conducted in cooperation with a variety of international partners. MORABA offers a number of mechanical and electrical systems for use on rocket , balloon and short term satellite missions. Depending on the scientific objectives, an appropriate launch range is selected and complemented or fully equipped with MORABA's mobile infrastructure, such as launcher, telemetry, telecommand and tracking stations. MORABA procures the suitable converted military surplus or commercial launch vehicles, as well as all necessary mechanical and electrical subsystems to the customers. This paper gives at first a short overview over MORABA's tasks in general, and the most important milestones in the history of MORABA. After that, we describe the capabilities which MORABA offers to fulfil scientific flights on sounding rockets. We also describe shortly some recently developed technology, which will be used in upcoming sounding rocket missions.

I. INTRODUCTION

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 experiments, hypersonic research, technology testing and 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 (Sweden), Andøya Rocket Range and Spitzbergen (Norway), Natal and Alcântara (Brazil) as well as Biscarosse (France), 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 rocket motor systems are converted for 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 is a key competence of MORABA. A long standing collaboration with our partners in Brazil (DCTA and IAE) offers a unique ability to directly tailor the design of new rocket motor systems for research purposes.

A further objective of MORABA is the development, fabrication and testing of commercially unavailable mechanical and electrical components and systems for sounding rockets and balloons as well as for short duration satellite missions. An example for such a mechanical system will be given below in the description of the mechanical systems.

In accordance with its key work areas, MORABA is structured into five groups as shown in figure 1, covering telemetry and RADAR for status and trajectory information, electronic and mechanical flight systems, launch services and flight dynamics as well as business development and tender preparation.

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 Bureau Veritas.

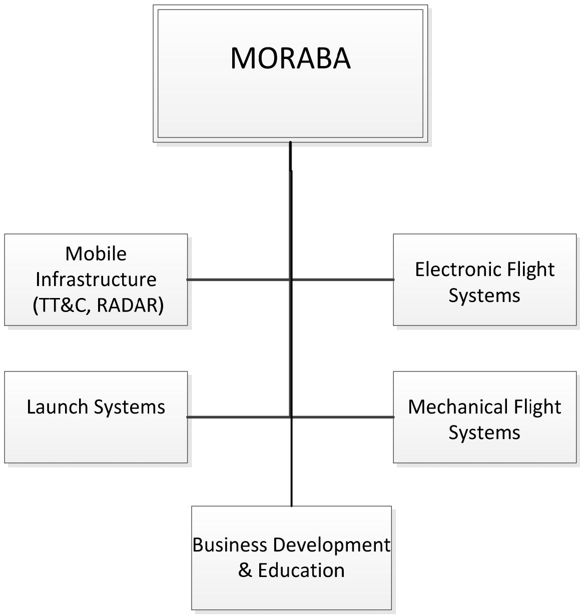

Figure 1MORABA Organization

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 funded by the German Federal Ministry of Economics and Technology (BMWi), the DLR Space Administration and ESA.

Furthermore, MORABA is intimately connected with international partners. So, EuroLaunch[3] is a cooperation between the German Aerospace Center (DLR) and SSC in the field of sounding rocket and balloon activities. The EuroLaunch agreement between both partners was signed on December 8th 2003 at Esrange Space Center. Both organisations have provided launch operation services to scientists and space organisations in Europe and worldwide since the late sixties. Within this cooperation, MORABA can use all common EuroLaunch facilities. A second cooperation is with the Brazilian partners DCTA and IAE for more than 40 years.

II. SHORT OVERVIEW OF THE HISTORY AND MILESTONES

The Mobile Rocket Base (MORABA) was founded in 1967 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 Extraterrestrial Physics. MORABA was later, in 1969, integrated into the DFVLR now DLR and is based in Oberpfaffenhofen, Germany.

MORABA's first campaign concerned the provision of a launch service in Euböa, Greece, for a scientific mission to investigate a solar eclipse. Within a window of two hours, MORABA launched five Sparrow Arcas rocket vehicles, five single stage Arcas and two Centaure-rockets.

For this first mission MORABA was only launch provider and did not provide recovery. Service Systems and payloads were built by the experimental groups and the company Kayser-Threde. For subsequent missions, attitude or rate control of the payloads were frequently required and a variety of systems were used from several companies in Europe and the USA. These included the ASTRID (2 axis) and DACHS (3 axis) inertial systems from Dornier System, and the MIDAS inertial platform based systems from Space Vector, as well as the Stage 1 sun pointer systems from MSDS in England. In the early seventies, MORABA attained the capability to develop and construct all of its rate and attitude control systems except the UNISTAB two axis inertial system from Dornier System, the TEXUS rate control systems from Kayser Threde and the guidance and payload control of the Aries vehicles launched from Kiruna, Sweden.

Apart from rate control systems for microgravity research, the main requirements for astronomy missions were inertial systems which used the MIDAS and later the DMARS-R inertial platforms for absolute pointing accuracy of the order of 2° or in combination with star trackers for two axis accuracy of better than 2 arc minutes.

A further requirement for large scans and the use of experiment sensor data to modify and correlate pointing manoeuvres during the short mission time of the order of 6 minutes, led to the development of techniques for the incorporation of interactive "man- in-the-loop" control. The first application of this feature was in the ASTRO 7 mission in 1977. The control system operator was able to react to the actual events during a complex scan manoeuvre and optimise the pointing of the experiment via telecommand. This technique has subsequently been used in many of our control systems and has resulted in an optimization of the experimental results and is several cases has enabled the rescue of a mission where some problem with the vehicle or sub-systems would have compromised the mission.

During the next decades, MORABA performed a large number of campaigns all over the world, with increasing focus on microgravity. MORABA now also performs recovery on land as well as at sea, using special recovery systems with floating devices for the sea recovery.

Nevertheless, its ability to react quite fast MORABA proved during the SUPERNOVA campaign. The aim of this mission was observation of the remains of the Supernova 1987-A. Within a time-frame of only five month, MORABA completely designed and constructed a payload for this purpose and did a launch campaign in Australia.

The SHEFEX I +II missions (Sharp Edge Fligth Experiment) used all of MORABA's technical capabilites to perform some sophisticated manoeuvres with the rocket. Their goal has been to test and qualify cost effective re-entry thermal protection technology in a flight experiment. For this reason the payloads had to reenter into the atmosphere in a well-defined orientation. During the SHEFEX II mission it was the first time, that the vehicle was actively guided during flight by MORABA.

III. SCIENCE ON SOUNDING ROCKETS - SOUNDING ROCKET FLIGHT TICKET

MORABA is providing sounding rockets for different research areas, among them astronomy, hypersonic research, metereology and fundamental physics. MORABA also supports student education within the programs REXUS/BEXUS as well as the STERN-program from the German Space Management.

MORABA offers a sounding rocket flight ticket for scientific missions. This includes all the necessary tasks for the successful mission, i.e. beginning with mission management, campaign planning and range coordination, integration, assembly and testing of the payload up to the fulfillment of the campaign itself including the launch of the vehicle and recovery operations if required. MORABA also provides preflight reports and postflight mission analysis.

An more detailed overview over all the steps involved as well examples for ongoing scientific missions can be found in the paper [1].

IV. SOUNDING ROCKET TECHNOLGY DEVELOPMENTS

MORABA uses a variety of systems for their sounding rocket missions. All systems can be developed further, especially if there is a special need by the customer. On the other hand MORABA provides systems, which are capable to master a lot of different tasks, as the Multi-Function-Card for electrical housekeeping and data mangement described below. The systems can be divided into several categories:

Launch Systems

For truly independent launch operations at remote locations, MORABA maintains and operates one mobile sounding rocket launcher system. The single rail launcher is used for vehicles with a mass of up to six tons. For weather and wind protection during the preparation phase, the launcher can be covered by a tent which is movable on railway tracks. The launcher is remotely controlled from the launch control room. Alternatively, there exists a completely mobile container from which the launcher can be manouvered.
The launch team also provides the motor hardware consisting of tailcans, fins and interstage adapters.

Mechanical Flight Systems

Mechanical Flight Systems take care of the overall rocket mechanical systems and especially recovery, if needed by the customer. Main part of the recovery system is the parachute itself. Its housing is the so called recovery-system as part of the payload. This system also provides the electronics and mechanics for proper recovery operations. The recovery system can be at different locations of the rocket, according to the requirements of the payload. For launches over the sea, a water recovery system with floating devices is also available.

Figure 2WADIS-2 Vehicle

If necessary, MORABA is also able to construct and build special mechanisms for scientific purposes.

So, as an example, for the WADIS 2-mission an ejection mechanism for the MSMA-experiment was constructed. The MSMA experiment is a free falling, football sized, sphere performing measurements in the middle atmosphere. In order to use excess capacity in the motor adapter of the VS30 launch vehicle it flies "piggybag" together with the WADIS 2 main payload.
Due to technical reasons the MSMA ejection sequence cannot be directly triggered by the vehicle's internal ignition system, thus it is mechanically coupled with the WADIS 2 payload separation occurring at approx. 60km altitude. Its predefined ejection vector is normal to the vehicle's longitudinal axis preventing any collision with the main payload. For structural stiffness and stability reasons the payload separation interface is used as the ejection opening instead of an additional cut out in vehicle's outer hull. Therefore a canister, carrying the MSMA sphere, is lifted by springs from the bottom to the top of the motor adapter almost in parallel of the main payload separation sequence.

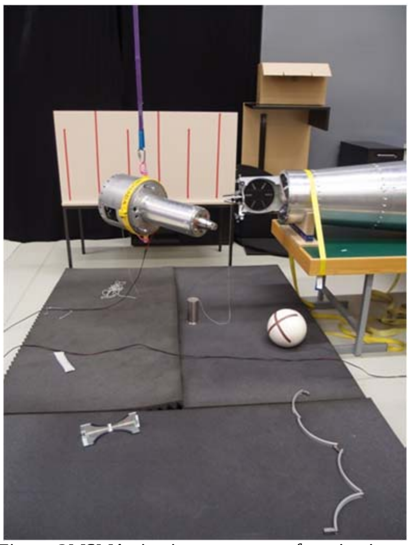

Figure 3MSMA ejection test setup after ejection

Electrical Flight Systems

The electrical flight systems group is, among others, mainly responsible for scientific data management and housekeeping. For this, MORABA provides the Service Systems. The Service Systems are parts of the payload systems that process the scientific data to generate a telemetry stream for sending to the ground station during the flight.

MORABA already uses a so called Multi Function Card (MFC2) in the Service Systems for data management. MFC2 was developed within the last years and extended the capability of the formerly used MFC1. It is based on a BLACKFIN BF651 digital signal processor combined with a FPGA (Altera Cyclone III). This card provides a direct TM/TC interface, generic line drivers for serial communication and 10/100 Base-T ethernet to the customer. The BF651 is used for advanced control algorithms and data compression algorithms (e.g.) digital video. The FPGA serves as a periphery and communication controller as well as for data pre- and post processing and data management. Housekeeping circuits monitor voltage, current and temperature within the system. The card's clock-pulse is 20MHz in the base band for the bit frequency. Transmission of data is now only limited by the transceiver bandwith. Several transceivers can be fed with different data streams handled by the MFC2. Furthermore, the card offers flexibility in the number of TM-transmitters.

Rate Control and Attitude Control Systems are also used if required. In general, an RCS can control the motion in all three axes to compensate for centrifugal forces. Usually, the RCS is stopped at a rate of 0.1° in the roll axis and about 0.5° around the lateral axes. For the RCS cold gas is used. An RCS is used for most microgravity projects and mission, as TEXUS and MAPHEUS for example.

Attitude Control Systems are used to point the rocket into a certain direction. Normally this is done up to an accuracy of 2°. In combination with an inertial platform it is possible to give the rocket any desired direction and attitude. For the SHEFEX II mission in 2012 a precession control maneuver was fulfilled to give the rocket a desired orientation. These maneuvers have been steered via the control algorithms implemented in the DMARS-platform. The MAIUS-1 mission (see description below) will also need these possibilities to vary the rockets attitude for successful physical measurements.

Figure 4 DMARS Inertial Platform

Telemetry and Telecommand

MORABA maintains and operates two fully containerized mobile telemetry and telecommand stations in the S-band frequency spectrum. These stations can be set up at any site on the planet. They are self-contained and adaptable to a variety of configurations. Multiple telemetry and TV links can be supported simultaneously. All necessary equipment, for demodulation and recording of FM, PM, PCM and real time TV signals is included in the stations. Signal decommutation and conditioning is also performed. Real time quick look and post flight replay is available. Each station is equipped with all necessary instrumentation and support electronics to track and command sounding rockets, balloons or satellites.

The new telemetry station of the DLR Mobile Rocket Base (MORABA) is a fully equipped commanding, tracking, and data acquisition ground station developed particularly for sounding rocket and stratospheric balloon research, as well as a support system for satellite missions during launch and early orbit phases

Its primary design goal was maximum mobility and versatility. Hence, the station is optimized for easy transportation in standard 20 feet ISO containers, fast setup, and highest independence regarding location and infrastructure. It can be operated at tropical temperatures and arctic conditions alike.

The TT&C station comprises two independent antenna systems made by ORBIT Communication Systems. The main antenna features a segmented 5 meter parabolic dish on a very fast elevation-over-azimuth pedestal and an S-band tracking feed with supplementary acquisition aid. The feed supports simultaneous uplink and downlink in the S-band, both with polarization diversity for improved signal quality even under adverse conditions. A small 1.5 meter secondary antenna with autonomous tracking equipment provides backup to the main system for fast target acquisition and wide angle tracking capability.

Beside slant-range data that is made available by the telemetry station and the GPS position data from the vehicles housekeeping data, a mobile instrumentation RADAR (RIR-774C) which operates in the C-band frequency spectrum allows precise trajectory determination for scientific and safety related purposes.

The radar RIR 774C is a completely mobile C-band (5.4 -5.9 GHz) monopulse tracking radar and has 640 kW maximum peak power.

The radar can be used to measure of flight trajectories for different kinds of targets such as rockets, planes, satellites, balloons etc. The instantaneous position is measured 50 times a second with a high accuracy and data are recorded. Accuracy in distance can be 10m at a signal to noise ratio of 10 dB.

There are two tracking modes available: Skin-mode and Beacon-mode. Within Skin-mode transmitted pulses are reflected from the target and tracking is by the reflections. For beacon mode an onboard-transponder is triggered by the received radar signals and sends output-pulses via the onboard antennas. In addition the radar has a video camera system with a fixed zoom of 1000mm, which supports the radar for optical star calibration. Tracking data can be used for real-time prediction of the impact point during the ascent of a sounding rocket. Based on this information the range-safety officer can decide to destroy the rocket in the case of a deviation from the nominal trajectory if the vehicle is equipped with a destruct system.

Figure 5 MORABA Telemetry Antennas and Station

The RIR774 is a completely independent system, whereas GPS requires a functioning telemetry, which makes it valuable for flight safety reasons as an additional tracking system. Even if there is a total data dropout from the rocket, the radar provides accurate data in the Skin-mode about the objects flight path.

Suitable software packages are available for post flight data evaluation, which is essential for the processing and altitude correlation of many scientific experiments.

The radar consists of 2 base containers (electronics and pedestal) and two additional containers (storage and laboratory).

V. SELECTED EXAMPLES FOR FUTURE MISSIONS

MAIUS

MAIUS, a matter-wave interferometer that will be launched on a sounding rocket, will generate the first BEC (Bose-Einstein-Condensate) in space and investigate it over a lengthy period of time. Carried by a research rocket especially configured by MORABA, see figure 8, MAIUS is scheduled to be launched from Esrange near Kiruna in the north of Sweden in November 2014. During the microgravity phase of the flight, which will last for six minutes, researchers expect to enter territory that has not been explored so far in quantum physics experiments. To put the matter in perspective - under normal gravity, a BEC can be maintained in a laboratory for no longer than a few fractions of a second. This is why physicists regard this rocket flight as a milestone. During the prolonged phase of microgravity, they will be able to generate not only one but several BECs in succession and study them for a period that is much longer than anything that has been achieved so far – a project that is unique worldwide [5].

VLM

VLM (Veículo Lançador de Microsatélites) is a planned launcher for microsatellites. It is foreseen as a three stage rocket and shall be able to carry payloads up to 200kg mass into a low earth orbit. The first two stages will be S50-motors from Brazilian manufactury. For the planned SHEFEX III mission, the third stage should be an S44 motor, which was also used at the SHEFEX II mission. The S44 motor is made of aromide, which makes it much lighter than a steel motor case. Both first stages will have a thrust vector actuation system for active control of the flight. VLM is also provided with DMARS-platforms and a cold gas system. This cold gas system will be used for control of the third stage. The system is controlled automatically, but can be overruled manually in emergency case. VLM will have a length of about 19 meters and a total lift off mass around 28.5 tons.

VI. SUMMARY & OUTLOOK

Sounding rockets and balloons will continue to provide a flexible, cost and time effective platform for various fields of scientific research for experiments qualification and for verification measurements. Beside the development of new vehicles for microgravity experiments another challenge is the continuously increasing data rate of new experiments and the bandwidth of the telemetry and telecommand systems. The need of teleoperations on experiments during a flight mission and the provision of real time telemetry data on flights with high apogees or long range will become more important in the coming years. Improvements on the ground equipment and telemetry stations are necessary to serve the demands of future experiments.

In future projects MORABA will be more involved into control systems and the need of teleoperations on experiments during a flight mission. In consequence MORABA will further improve its competence and capabilities in these directions.

VII. ACRONYMS

BEC	Bose-Einstein-Condensate
BEXUS	Balloon Experiments for University Experiments
BMWi	Bundesministerium für Wirtschaft und Technologie
BPSK	Binary Phase Shift Keying
DCTA	Departamento de Ciência e Tecnologia Aeroespacial
DLR	Deutsches Zentrum für Luft- und Raumfahrt
ESA	European Space Agency
ESRANGE	European Space and Sounding Rocket Range
FM	Frequency Modulation
GPS	Global Position System
IABG	Industrieanlagen-Betriebsgesellschaft mbH
IAC	International Astronautical Congress
IAE	Instituto de Aeronaútica e Espaço
ISO	International Organization for Standardization
ISS	International Space Station
MAIUS	Materie Interferometrie Unter Schwerelosigkeit
MAPHEUS	Materialphysikalische Experimente unter Schwerelosigkeit
MORABA	Mobile Raketenbasis
MSMA	Mess-System Mittlere Atmosphäre
OHSAS	Occupational Health and Safety Assessment Series
PCM	Pulse Code Modulation
PM	Phase Modulation
RADAR	Radio Detection and Ranging
REXUS	Rocket-borne Experiments for University Student
RIR	Range Instrumentation RADAR
SCRAMSPACE	Scramjet-based Access-to-Space System
SHEFEX	Sharp Edge Flight Experiment
SNSB	Swedish National Space Board
STERN	Studentische Experimental-Raketen
TC	Telecommand
TM	Telemetry
TT&C	Telemetry, Tracking & Command
TV	Television
VLM	Veículo Lançador de Microsatélites
WADIS	Wellenausbreitung und Dissipation in der Mittleren Atmosphäre

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