MORABA – Operational Aspects of Launching Rockets

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Mobile Rocket Base (MORABA), a division of the Space Operations and Astronaut Training Department of DLR (German Aerospace Center) 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, astronomy, geophysics, material science and hypersonic research and are conducted in cooperation with a variety of international partners. In addition satellite missions can be supported by mobile tracking radars for trajectory determination and TT&C (Telemetry, Tracking & Command) mobile ground stations. MORABA also offers a number of mechanical and electrical systems for use on rocket, balloon and short term satellite missions. Since 1967 more than 250 campaigns have been performed in Antarctica, Australia, Brazil, France, Greenland, India, Italy, Japan, Norway, Spain, Sweden and the USA. 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 an overview of the MORABA infrastructure for sounding rocket launching and satellite TT&C. A short survey of MORABA support of several satellite projects in the past is also provided.

I. Introduction and Overview over MORABA

THE Mobile Rocket Base (MORABA) was founded in 1967 as part of the Max Planck Society under the initiative of Professor Reimar Lüst. MORABA was later integrated into the DLR and is based in Oberpfaffenhofen, Germany.

MORABA's main task is to support the national and international research communites 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, hypersonic research, technology testing and education. By providing and operating mobile infrastructure (TT&C 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 local 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 the use as sounding rockets and commercially available systems are acquired as necessary. The cost-effective combination of

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Figure 1. MORABA Operation, Research & Development Fields

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, see section VI B) offers a uniqe ability to directly influence 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.

The key work areas of MORABA are shown in Figure 1. In accordance with these work areas, MORABA is structured into four groups as shown in Figure 3, covering telemetry and RADAR for status and trajectory information, electronic and mechanical flight systems as well as launch services and flight dynamics.

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.

Primary customers of MORABA's expertise and facilities are universities and research institutions, 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, the DLR Space Administration and ESA.

II. MORABA Infrastructure for Operations

MORABA has all necessary mobile infrastructure to setup and support worldwide sounding rocket missions. During the design of the various stations, special attention was given to mobility and suitability for the extreme environmental conditions encountered at the potential launching sites.

A. Telemetry and Telecommand Station

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.

Figure 2 TM Station with Antenna

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. The following we give some specifications of the MORABA TM-station:

Station Specifications:

Power Supply:	Mains: 3 Phase 400V or 200V 63A
	Backup: 3 Phase 400V 63A IT-Net
Power Redundancy:	Automatic switching between Mains/Backup
	UPS for sensitive Rack Equipment
Air Conditioned:	two separate A/C circuits for Rack Equipment and Personnel
Antenna Control Units:	2 Orbit AL-4000 ACU (Antenna Control Unit)
Receiving Equipment:	6 Cortex RTR Dual Channel TM Receivers
	4 Intus Dual Channel TV Receivers
Recording:	2 Wideband DRS3000

Antenna Specs:

Dish size:	5m
3 dB Beamwidth:	1.8°
Gain:	38 dBi
Feed Type:	Main: 5 element prime focus
	Acquisition: 4 cavity backed elements
Tracking Type:	Main: E-Scan
	Acquisition: Single Channel Monopuls
Scan Rate:	500 Hz
Receive Polarity:	LHCP and RHCP
Receive Frequency Range:	S-Band: 2200 – 2400 MHz
G/T:	14 dB
Transmit Polarity:	LHCP or RHCP
Transmit Frequency Range:	S-Band: 2000 – 2100 MHz
Max. EIRP:	52 dBW

Pedestal Specs:

Pedestal Motion Type:	Elevation over Azimuth
Drive Type:	Dual Servo Drives
Movement Range:	Azimuth: unlimited
	Elevation: -3° to 183°
Max. Velocity:	25°/s
Max. Acceleration:	25°/s^2

Environmental Specs:

Temperature:	-40°C to +50°C operational
Wind:	80 km/h operational
	180 km/h stowed
Min. ground requirement:	Solid Gravel (strip foundation for Antenna, if higher wind speeds expected

B. RADAR Tracking

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.

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).

C. Monorail Launcher

For truly independent launch operations at remote locations, MORABA maintains and operates one mobile sounding rocket launcher system, see Figure 3. This 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.

D. Laboratory

At its home base in Oberpfaffenhofen, Germany, MORABA maintains a dedicated laboratory area with various technical test facilities (i.e. thermal-vacuum test chamber, three-axis air bearings) and checkout systems. Bench tests and flight simulation tests are performed in the MORABA laboratory. With the three-axis air bearing tests of attitude and rate control systems can be performed.

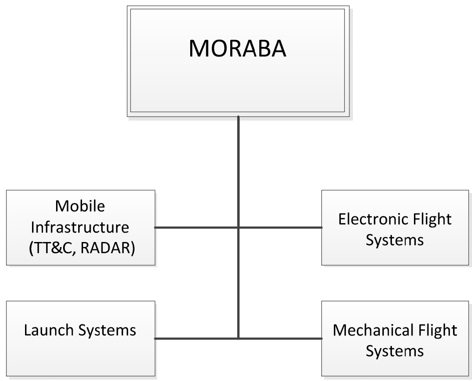

Figure 3. MORABA Organization

III. Mission Preparation and Operations

For missions conducted within the national space program, MORABA is usually contacted by the primary investigator in the early stage of a project. MORABA provides assistance in defining the mission objectives, selecting suitable sounding rocket vehicles and optimum launch locations. The necessary electrical and mechanical subsystems that are required to meet the mission objectives (e.g., telemetry, recovery) are identified as vital components for the mission scenario. Finally, MORABA provides preliminary costings and implementation plans as input for the scientist's project proposal to the funding agencies. Aside from national scientific organisations, MORABA is contacted by commercial customers in response to conference presentations, international contacts or cooperation.

This section describes the usual workflow for the preparation and conduct of a typical sounding rocket or balloon mission from project acquisition to vehicle launch.

A. Mission Management and Range Coordination

Prior to any mission, negotiations with range authorities are conducted to obtain the necessary launch permissions, to define the local infrastructure facility requirements and to determine logistics requirements. Depending on the range location and existing instrumentation, an optimal ground station configuration and ground support equipment setup is defined. Any deficiencies are supplemented by MORABA mobile equipment. Where required, comprehensive self-contained launch facilities are made available for deployment at remote locations, requiring only minimum on-site preparations.

B. Assembly, Integration and Testing

A large variety of sounding rocket payloads and components can be assembled, integrated and tested in the MORABA laboratories. All necessary equipment and test setups are available to verify transmitter and receiver systems as well as scientific and support system data integrity. Facilities are available to test rate or attitude control systems for a wide range of payloads, including three axis air bearing systems. This allows realistic calibration and verification of the pointing accuracy and the required manoeuvers during the ballistic flight phase in the heterosphere (> 100 Km). To facilitate the testing process, dedicated or generic electrical ground support equipment is designed and constructed. For environmental testing, payload spin balancing and determination of the payload's physical properties, MORABA uses industrial test facilities (EADS Astrium, IABG and the University of the German Federal Armed Forces in München, Germany[2]).

C. Launch Campaign and Operations

After the successful completion of the bench tests, flight simulation test and the environmental tests, all necessary equipment, mobile stations and flight hardware are transported to the selected launch location. Station assembly, motor preparation and payload integration are performed in parallel to reduce the time-to-launch. After completion of the preparation phase, an intensive test period follows to ensure the readiness of all participating organizations and flight systems.

After the test countdown, one or more so called "hot" countdowns are needed to launch the rocket vehicle. The number of countdowns is, besides potentially appearing technical problems, dependent on the weather conditions and scientific constraints. For ionosphere research, certain phenomena such as aurora borealis are necessary, to provide the proper scientific conditions for the experiments. In the case of microgravity missions, the launch opportunity is mainly influenced by local weather conditions. After the parachute recovery system sequence and the safe landing of the payload, it is retrieved by helicopter or ship and brought back to the range.

Figure 4 Mobile MAN-2 Launcher

From the beginning of flight, the TM-station and the RIR774 track the rocket on its flight path. To support the tracking, the TM antenna can also follow the pre-calculated nominal flight trajectory until tracking is achieved. The radar is supported by an optical tracker, called "open sight". During flight, radar follows the trajectory and TM receives all the flight data sent by the rocket, including the GPS-position. If necessary, TM sends commands for experiments or attitude and rate control. Data from the Service system are monitored during the flight. At the end, recovery data are monitored until the rocket impacts or telemetry is lost due to features of landscape in the impact area such s mountains etc.

D. Pre- and Post-Flight Mission Analysis

A major part in the preparatory phase of launching sounding rockets is the pre-flight mission analysis. Depending on the physical properties of the payload and the selected launch vehicle, an iterative analytical process is performed to tune and verify the required flight performance with regards to trajectory, stability, heating and re-entry. For range safety and recovery purposes, a dispersion analysis is also performed.

After the flight, all available flight data from various sources, such as radar, slant-range, housekeeping data inclusive inertial platform navigation and GPS data are processed and compared to the predicted values. Any deviations and anomalies are investigated and if necessary design and procedural changes are implemented.

IV. Sounding Rocket and Balloon Mission Portfolio

In the following chapter some significant missions in recent past and ongoing missions are described. During the last five years more than 40 sounding rockets and 10 balloon flights have been launched with participation or within a "flight ticket" of MORABA, from various locations worldwide. Only major missions are addressed in the following subchapters. We also describe the operations during the SHEFEX-II mission.

A. Atmospheric Research

[2] University of the German Federal Armed Forces

MORABA supports and operates sounding rocket missions for atmospheric research. Exemplary for this is the ECOMA – mission (Existence and Charge State of Meteoric Dust Grains in the Middle Atmosphere). Goal of the project is to determine the number density and altitude distribution of meteoric smoke particles in the middle atmosphere. This project was a bilateral project between Germany and Norway involving a total of 9 sounding rockets distributed over four campaigns from Andøya Rocket Range from 2006 to 2010[1,2,3,4].

A new atmospheric research project with two rockets is WADIS (Wave expansion and dissipation in the middle atmosphere). The first WADIS vehicle was launched in July 2013. After WADIS there will be an ongoing program, PMWE (Polar Mesospheric Winter Echoes).

B. Microgravity Missions

Physical experiments in Earth-based laboratories are very often negatively influenced by gravity. Material physics studies, for example, various processes in metallic alloys on an atomic scale. The corresponding experiments require “weightlessness” for high quality results. The suborbital parabolic trajectory of a sounding rocket offers experimental time up to 13 minutes under microgravity conditions. Example microgravity projects supported by MORABA among others are TEXUS (50 rockets up to now), MAXUS and MASER.

C. Testbed for Hypersonic Research

In addition to the regular microgravity and atmospheric research programs, there is a growing interest in the use of sounding rockets for performing complex flight experiments in the field of hypersonic research. In contrast to hypersonic wind tunnels, sounding rockets can provide up to one minute of Mach 10 conditions for relatively large experiments. This application requires new classes of vehicles and sub systems which are not readily available on the market.

Exemplary for this research area are the projects HIFiRE and SHEFEX.

The hypersonic research program HIFiRE (Hypersonic International Flight Research Experimentation) is an international hypersonic research collaboration supported by MORABA. The HIFiRE program entails the launch of up to nine research payloads with sounding rockets[5], of which MORABA provides launch services. With the launch of SHEFEX-1 (Sharp Edge Flight Experiment), the DLR MORABA demonstrated its capability to provide a cost-effective platform for hypersonic research during the re-entry phase of sounding rocket vehicles

D. SHEFEX-II Operations

SHEFEX-II was launched on a Brazilian two-staged S40/S44 rocket to achieve a higher velocity. Moreover, in contrast to its predecessor, SHEFEX-II had small wings known as canards, which enabled the craft to be maneuvered. From Andøya, SHEFEX-II reached an altitude of 200 kilometers. For the researchers, the interesting part was when it re-entered the Earth's atmosphere with a velocity of more than Mach 10. SHEFEX-II was tracked from the new MORABA telemetry station (see description above) located at the KEOPS-hill in Kiruna as well as from the RIR-774 radar station located at the launch site in Andøya. The tracking was supported also from additional stations on Svalbard. The onboard system generated a redundant PCM-data stream with 833kBit/s using two different S-band frequencies which the ground stations combined to a single stream.

SHEFEX-II was the first vehicle which was actively guided during the flight by MORABA, see the article by J. Ettl and J. Turner within these proceedings[6].

Education

Within the REXUS/BEXUS-project which is realized under a bilateral Agency Agreement between the German Aerospace Center (DLR) and the Swedish National Space Board (SNSB), student teams from all ESA member states are invited to apply for an experiment flight on a stratospheric balloon or a sounding rocket. Every year two balloons and two rockets are launched at the ESRANGE base in Kiruna in the north of Sweden. During a RX/BX-cycle students have the opportunity to learn the whole lifecycle of a space project and to get insight into different operational tasks during a rocket flight[7]. Via the onboard-telemetry of the rocket, the teams can receive their experimental data in real-time.

V. Technologies and Operational Support for Satellite Missions

Many subsystems that have originally been developed and employed for sounding rocket applications proved to be attractive for cost-effective, short duration satellite projects. The harsh environment during a sounding rocket launch with its high acceleration and vibration profile, encouraged further investigations. Radiation related problems

could be successfully solved with dedicated tests, as reliable data for off-the-shelf components are not available. It could be demonstrated that "Sounding Rocket Technology" is applicable to many short duration satellite projects.
In addition to this benefit for testing satellite components on sounding rockets, MORABA also supported in the past some satellite mission with their TM/TC and Radar stations. In the following we describe briefly the support during these missions.

A. INSPECTOR

Inspector 1 (or X-MIR Inspector) was a free-flying remotely controlled small camera satellite (mass 72kg), with autonomos supply systems, which was launched onboard a cargo Soyuz-U (Progress M-36) to the space station MIR The intention was to fly around the MIR and to image the space station complex. Inspector 1 was launched on 05th of October 1997 and was intended to work for about one month. Unfortunately it failed to orient itself and did not react to commands, so operation was cancelled. DLR MORABA built the TV RF board system as well as the RF-reveiver system on the MIR station as a subcontractor of DASA (Daimler Aerospace AG). This systems would have operated the camera if the satellite had functioned.

B. EXPRESS

This was demonstrated as part of the EXPRESS (EXPerimental Reentry Space System) re-entry mission, for which MORABA developed the complete on-board TT&C-system and deployed its mobile telemetry, telecommand and radar stations at the remote Tjaliri site in Australia. MORABA built a complete Down Range with its C-band radar and S-band telemetry station. Express was expected to land after 5 days in Australia. Express was launched from Kagoshima (Japan) and was planned for a 5-day orbital mission. It launched with the Japanese 4-stage rocket M-3 SII on 15th of January. Due to a failure of the second stage motor the EXPRESS reentry capsule got lost only after 2.5 orbits. After nearly one year it was discovered in Ghana where it descended hanging on its parachute. It was recovered and flight data have been post processed. After this investigation it was clear that a DLR-reentry tiling experiment worked nevertheless successfully and the onboard computer stored all data during the reentry phase.

Figure 5 RIR-774 Radar

C. BIRD

For the BIRD micro-satellite, MORABA has developed, manufactured and tested the onboard TM/TC unit including the RF transmission and receiving and antenna system. Originally designed for a life time of less than two years, these systems are still operational after 10 years in orbit. Additionally, well proven PCM data handling subsystems and command logic have been transferred into the spacecraft onboard computer. Furthermore, the mobile S-Band telemetry and command stations were integrated into a ground station concept and used for the first acquisition of the satellite after its launch from India. MORABA also supported the operation of BIRD during the LEOP-phase. For this, on the pedestal of the radar, a telemetry antenna was mounted and positioned in Kiruna. Stations in Weilheim, Fairbanks (operated by PrioraNet) and Neustrelitz, also supported the mission. MORABA personnel monitored the telemetry from the K2 control room of the GSOC (German Space Operations Center) during LEOP.

VI. International Cooperation

A. EuroLaunch

On December 8th, 2003 DLR and SSC signed a cooperation agreement concerning joint activities in the fields of sounding rockets and balloons. This agreement was a continuation and strengthening of an agreement from 1994. The aim of this agreement is to establish a frame for the coordination of their activities, the exchange in the provision of services for sounding rockets and balloons activities towards third parties, with a view to consolidate competence of personnel and utilization of facilities and equipment for the services currently provided by their technical centers SSC Esrange and DLR MORABA. Successful teamwork has been demonstrated with launches of the student rockets REXUS and student balloons BEXUS[8].

B. DCTA/IAE

A frame agreement between the governments of the Federal Republic of Germany and the Federal Republic of Brazil on cooperation in the field of scientific research and technology development was signed as in 1969. By now MORABA looks back on a long history of joint sounding rocket projects with DCTA (Departamento de Ciência e Tecnologia Aeroespacial) and IAE. Many German sounding rocket missions have been performed from the Brazilian CLBI and CLA launch sites. A regular exchange of personnel within various projects has led to a broad competence, encompassing from designing and qualifying complete sounding rocket vehicles to implementing state of the art rocket flight design and analysis programs.

VII. Conclusion & Outlook

Sounding rockets and balloons will continue to provide a flexible, cost and time effective platform for various fields of scientific research for experiment qualification and for verification measurements. Besides the development of new vehicles for hypersonic research, 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 and possible satellite mission support.

Appendix A
Acronym List

BEXUS	Balloon Experiments for University Experiments
BIRD	Bi-spectral IR Detection
CLA	Centro de Lançamento de Alcântara
CLBI	Centro de Lançamento da Barreira do Inferno
DCTA	Departamento de Ciência e Tecnologia Aeroespacial
DLR	Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center)
EADS	European Aeronautic Defence and Space Company
ECOMA	Existence and Charge State of Meteoric Dust Grains in the Middle Atmosphere
ESA	European Space Agency
ESRANGE	European Space and Sounding Rocket Range
FM	Frequency Modulation
GPS	Global Position System
HIFiRE	Hypersonic International Flight Research Experimentation
IABG	Industrieanlagen-Betriebsgesellschaft mbH
IAE	Instituto de Aeronaútica e Espaço
ISS	International Space Station
MORABA	Mobile Raketenbasis
PCM	Pulse Code Modulation
PM	Phase Modulation
RADAR	Radio Detection and Ranging
REXUS	Rocket-borne Experiments for University Students
RF	Radio Frequency
RIR	Range Instrumentation RADAR
SHEFEX	Sharp Edge Flight Experiment
SNSB	Swedish National Space Board
TC	Telecommand
TEXUS	Technologische Experimente Unter Schwerelosigkeit
TM	Telemetry

TT&C Telemetry, Tracking & Command
TV Television
WADIS Wellenausbreitung und Dissipation in der Mittleren Atmosphäre

Appendix B
Glossary

Launcher	Launch rail to launch sounding rockets.
Microgravity	The term micro-g environment or microgravity is more or less a synonym for weightlessness and zero-g, but indicates that g-forces are not quite zero but just very small
Payload	All modules above motoradapter including experiments, service system and recovery system
Rocket	Complete Rocket Vehicle.
Science Payload	All scientific modules including the experiments

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