MORABA Sounding Rocket Flight Experiments

Mobile Rocket Base
German Aerospace Center

DLR

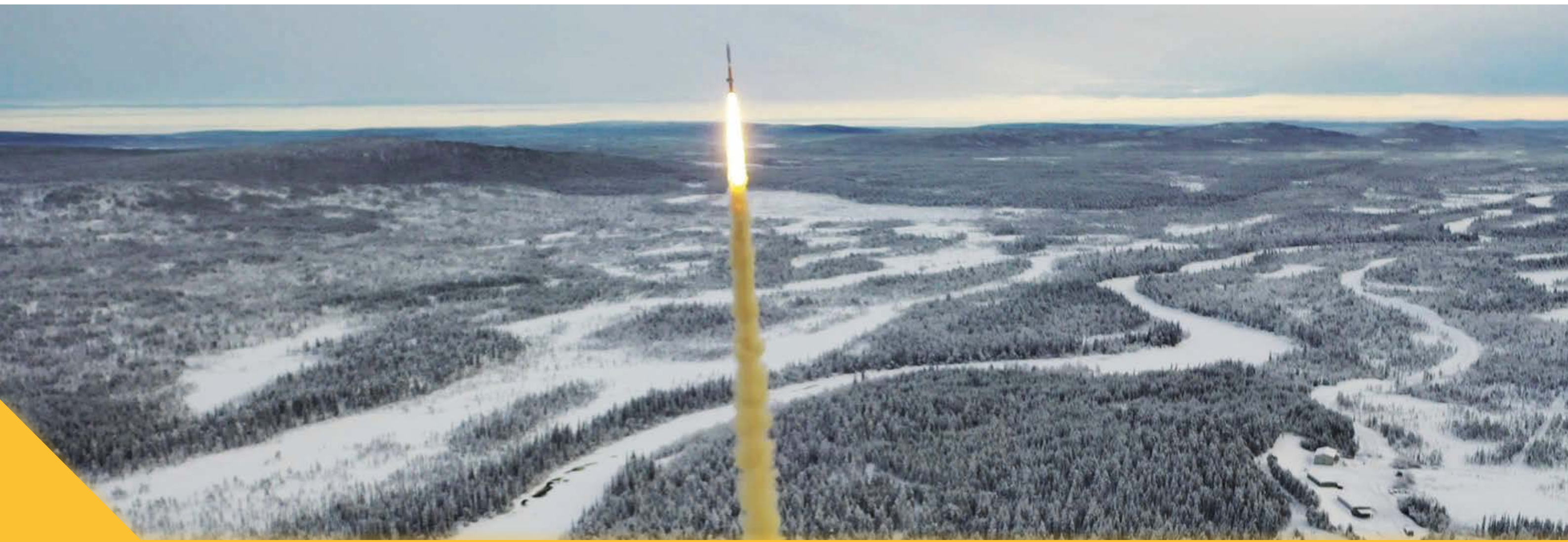

Fig. 1-1 TEXUS-56 Launch

MORABA at a Glance

Mobile Rocket Base ("Mobile Raketenbasis" MORABA) is a department of Space Operations and Astronaut Training of the German Aerospace Center, based at Oberpfaffenhofen. MORABA has been supporting scientific research missions with unmanned rocket and balloon based experimental platforms, and has been developing the mechanical and electrical vehicle systems as well as mission logistics required for these extraordinary purposes since the 1960s. MORABA has developed a unique mobile infrastructure and hardware for the planning, preparation and implementation of sounding rocket projects.

Fig. 1-2 MORABA Research Areas

In principle, MORABA is able to launch sounding rockets from anywhere in the world at short notice. Its experience and competence are valued and sought after by national and international research facilities, industry and institutions of higher education and research and development. The sounding rocket- and balloon-borne experiments cover a variety of scientific fields, such as atmospheric physics, microgravity, hypersonic research, technology testing and education (see Fig. 1-2). MORABA selects the launch range and designs trajectories in coordination with the scientific user and according to the specific scientific requirements (see Fig. 1-3). Parabolic up-and-over trajectories are the best choice for most microgravity as well as atmospheric physics missions. For the former, the experiment timeframe is during the free-fall phase of the flight. For the latter, the respective regions of interest in the atmosphere are traversed and examined during ascent and descent though these regions. For hypersonic research, suppressed trajectories are often preferred in order to achieve extended experimental times within the atmosphere at high Mach numbers. Requirements for technology testing, however, vary a lot. Flight profiles and carrier systems as well as launch sites are chosen individually. Sounding rockets of student programs often do not reach the Kármán line. Several national and international research program funding lines are active, mainly for microgravity research, e. g., in the fields of material sciences, astronomy, geophysics or life sciences. Other research areas are often supported through individual programs by the European national space program funding schemes.

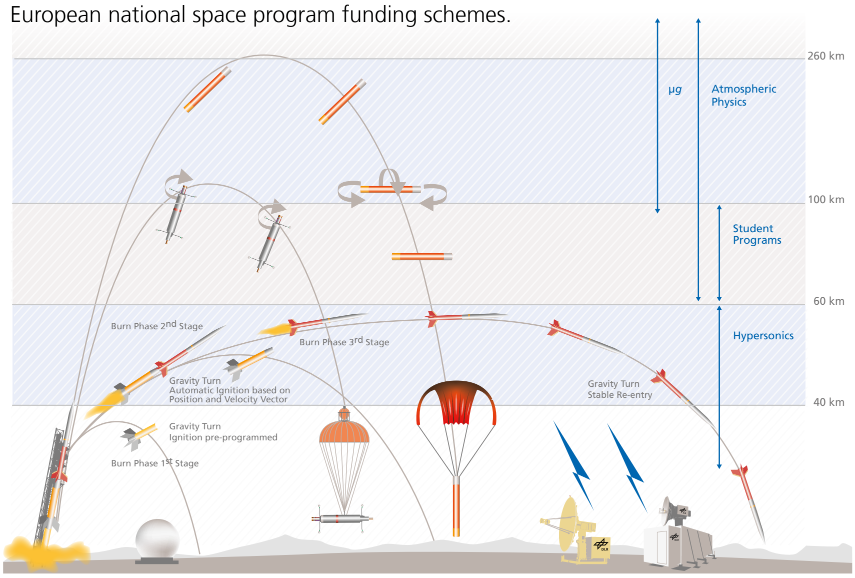

Fig. 1-3 Research areas with different altitudes of interest.

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2. End-to-End Service for the Research Community

A suborbital flight mission requires a variety of tasks to be completed in preparation and conduct of the launch mission itself, all culminating in the ignition of the first stage rocket motor. Dependent on the experimenters' needs, MORABA either fulfils parts of a mission or is responsible for the planning and conduct of the entire mission. This approach is called "flight ticket" (Fig. 2-1). A post-flight report summarizes the main flight characteristics and performances – it is generally the last deliverable to the user.
The MAIUS project is an example where MORABA's responsibility extended to the mission management and range coordination, the electrical and mechanical manufacturing of all systems for the launch vehicle as well as the customized payload support systems. The assembly, integration and all tests in advance of the launch campaign as well as the coordination and conduct of the mission itself completed the flight ticket. Finally, the post-flight analysis of the sounding rocket platform's performance was in MORABA hands.
For the TEXUS program for example, the industrial main contractor is responsible for mission management and all payload-related systems. MORABA acts as a subcontractor for launch service, tests, recovery- and service-systems and post-flight analysis. MORABA thereby adapts its services and mission participation to the requirements of the partners and customers and offers support in all areas that concern the launch vehicle, but is also available to provide service with a clear interface that is limited to the launch vehicle only. However, MORABA is not acting as a manufacturer, provider or reseller of products, systems or rocket motors. Launches are conducted as a service which utilizes rocket motor systems owned by MORABA and spent in the service effort.

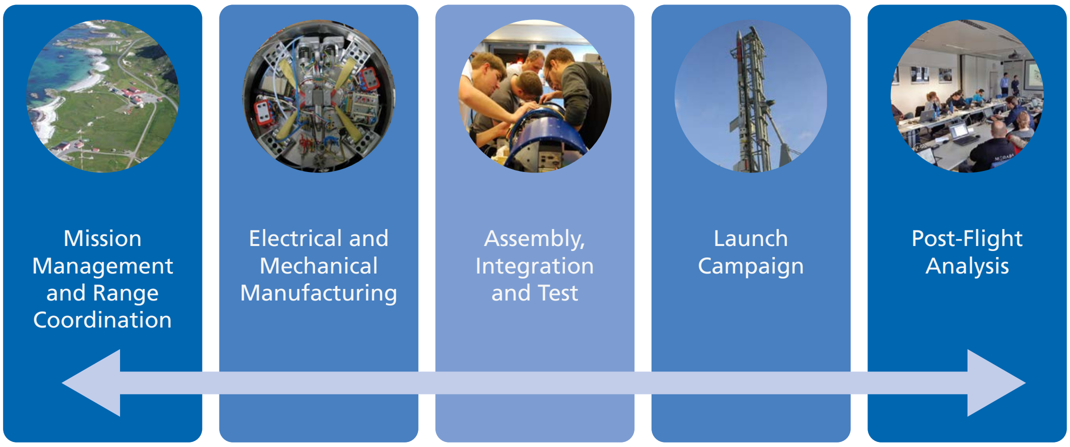


Fig. 2-1 MORABA End-to-End Service for Clients and Partners in a flight ticket approach

MORABA owns or has access to systems and infrastructure needed for its services and to perform successful launch missions and operations, including but not limited to
- a variety of rocket motors to be combined and integrated into a variety of in-house developed launch vehicles,
- the associated rocket motor and vehicle hardware,
- systems for power and information supply,
- payload support systems like cold gas systems, navigation and sensor systems, telemetry systems and recovery systems,
- a mobile launch and range infrastructure as well as
- comprehensive test infrastructure to perform all necessary functional and environmental testing in advance of the launch mission.

3. Scientific Platforms

3.1 Microgravity Experimental Platform

Physical experiments in most laboratories are frequently influenced negatively by gravity. In the field of material physics, for example, various processes in metallic alloys involve interactions on an atomic scale that can be "masked" or influenced by gravitational forces and/or the resulting effects and motions. The experiments investigating such interactions thus require "weightlessness" for high quality results. Experiments are also performed to investigate the influence of gravitational forces on biological processes. Several milli- and microgravity (µ*g*) research platforms with different characteristics with respect to experimental time and µ*g* quality are available in various laboratories and from several operators. The suborbital parabolic trajectory of a sounding rocket offers an experimental time of up to 13 minutes under high quality microgravity conditions of 10-5 – 10-6 g. During ascent, the rocket is aerodynamically stabilized and rotates along its longitudinal axis, it spins. At 70 km altitude, a yo-yo system eliminates the bulk of the spin, followed by further rotational stabilization of all three axes using a cold gas-powered rate control system. Once a predefined and minimized residual level of rotation is attained, the µ*g* experimental phase is initiated. This phase ends when the free-falling payload reaches appreciable atmospheric density upon reentry. During the subsequent descent, energy is dissipated to the atmosphere. The payload is finally recovered by a 2-staged parachute system after reentry.

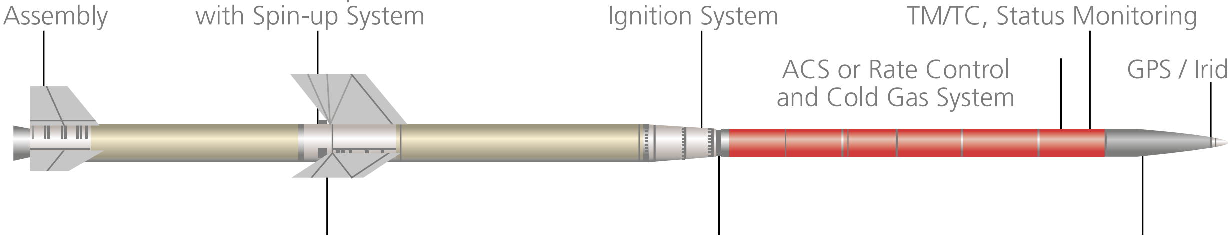


Fig. 3-1 Standard VSB-30 vehicle developed together with DCTA/IAE, Brazil, indicating different MORABA systems (grey labelling).

Microgravity missions can be launched from different launch ranges all over the world. Since land recovery is easier and cheaper when compared to any other recovery method, European microgravity missions mainly take place at Esrange, Sweden. A standard MORABA rocket vehicle system for this kind of missions is the VSB-30, but other rocket motor combinations are being used as well to create an unguided, fin-stabilized sounding rocket flight vehicle consisting of different subsystems. MORABA can provide all systems needed to perform customized microgravity missions including rocket motor systems, payload support systems as well as ground support systems.

The scientific experiments are integrated in experiment modules which are, together with payload support systems, recovered after flight (indicated in red, Figure 4). Experimenters and operational staff start a mission approximately 10 days before the first hot countdown. The experiments can be temperature controlled, and late access is possible until 30 min before launch if necessary. Telemetry and telecommand is possible throughout the flight. Figure 3-2 shows a typical microgravity trajectory showcasing the most important flight events and corresponding time points. The microgravity phase starts 1 min 15 sec after launch. Shortly before, a yoyo-despin system halts the spinning of the vehicle. After separation of the payload from the second stage rocket motor, a rate control system stabilizes the payload to achieve high quality microgravity conditions. In case the experiment has to be adjusted to a certain position, e.g. in a certain angle to Earth's center of gravity, an attitude control system is available. Apogee is reached after 4 min 20 sec at 260 km. After 15 min of total flight time, the payload touches down with a descent speed of approximately 7 – 8 m/sec in 70 – 80 km distance from the launch pad. The payload is recovered by a helicopter. Experimenters typically receive their samples back after approximately 1.5 h. In special cases it is possible for experimenters to join the recovery team and

handle the samples directly at the landing point around 20 min after the flight. Experiments and all subsystems are qualified to withstand the following conditions:
Standard microgravity missions provide 6 min of high-quality microgravity (10-5 – 10-6 g).

Max. acceleration:	12 g
Max. speed Mach:	6.5
Vibration:	5,8 Grms

Longer experimental times are possible, but require the use of guided vehicles in order to remain within the impact area despite the significant increase in apogee altitude. The MAXUS program employed a large guided rocket vehicle to reach a ceiling altitude of more than 700 km with a payload in excess of 700 kg.

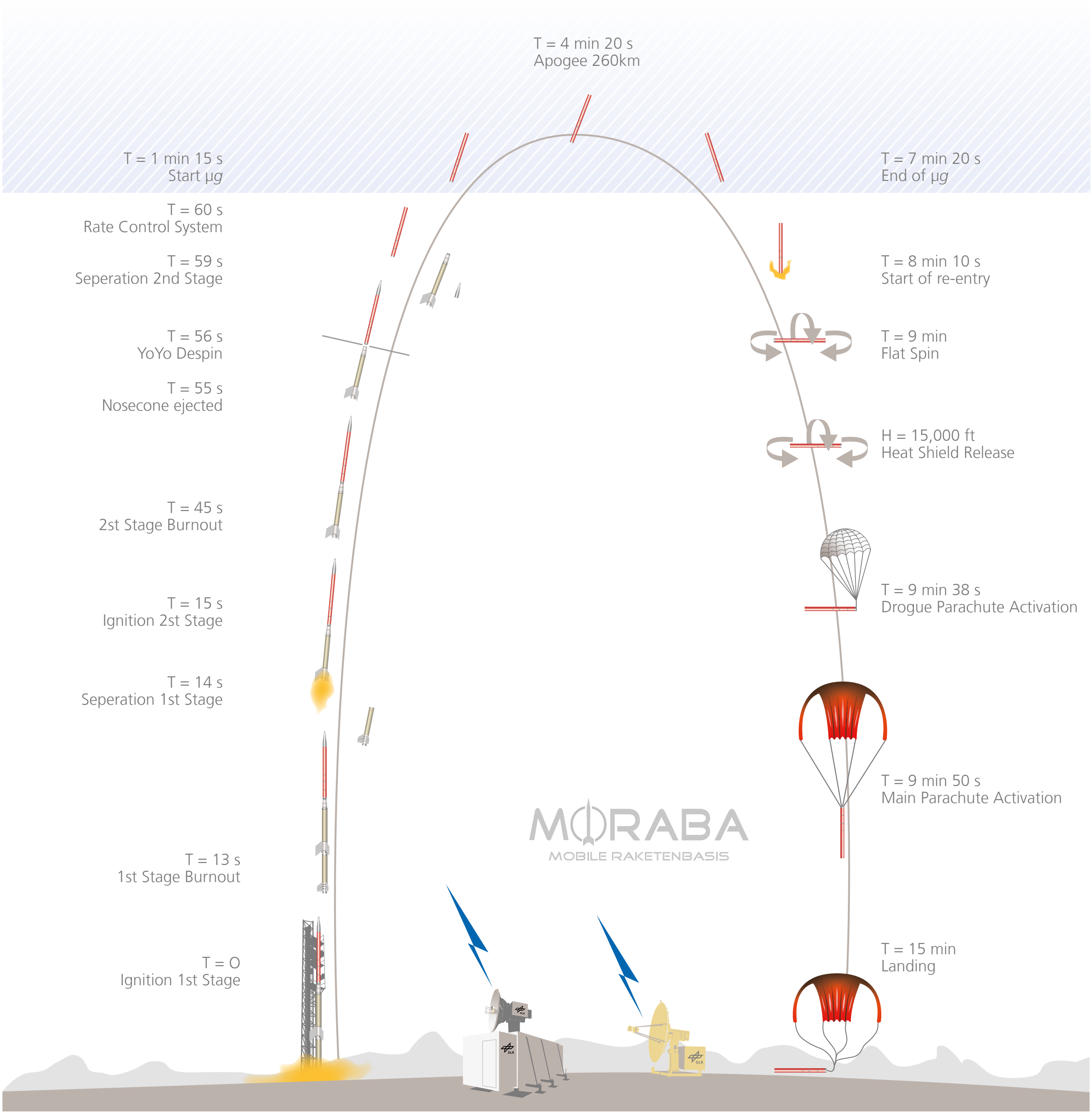


Fig. 3-2 Standard sounding rocket microgravity trajectory with flight events

3.2 Hypersonic Platform

Sounding Rockets have been essential for the support of technology development, microgravity and atmospheric physics research since the beginning of the space age. With research efforts increased to enable sustained hypersonic flight and provide optimized planetary atmospheric entry and re-entry systems, sounding rockets have become atmospheric research platforms for hypersonic experimentation. From the investigation of specific and basic aerodynamic and aerothermodynamic phenomenology up to sub scale flights of autonomous hypersonic flight vehicles, they offer a testing capacity that complements modelling, simulation and wind tunnel testing and fills the gap to full scale flight prototypes. Sounding rockets are adaptable, modular and low-cost flight platforms and allow fast implementation times from concept to experiment. In contrast to its ground-based counterparts, this flying experimental platform does not process the airflow by compression, expansion, combustion, arc heating or any other process that changes its chemical, thermal or physical properties. Further, achievable exposure times and flow enthalpies exceed the capacities of available wind tunnel infrastructure significantly. They allow a wide range of flight path types to meet many scientific requirements of hypersonic researchers. They can be seen as "flying wind tunnels".

DLR MORABA has been partnering this research since 2003, conducting a total of ten flight missions and currently projecting four more before the end of 2023. Launch vehicles as well as ground infrastructure have constantly been upgraded and customized to address the increasing demands regarding mechanical and thermal loads, TT&C coverage, flight control and safety.

The dream of travelling in hypersonic aircraft to get from one point on Earth to another in a few hours continues. However, Hypersonic aerodynamics and aerothermodynamics are also important for access to space and the aerodynamically controlled return and reuse of space launcher rocket stages and aerodynamic gliding vehicles.

Modern modelling and simulation tools are effective means to reduce development costs, but still require wind tunnel tests as well as realistic flight tests to verify and increase the prediction accuracy and clarify fundamental as well as specific aspects of general exemplary as well as complex integrated vehicle flow fields. Such tests must be conducted at meaningful scales as the combination of thermal and aerodynamic loads, both on a macroscopic and microscopic scale cannot be scaled from small to large vehicles in all aspects.

The following classification categorizes the hypersonic research technologies

- Aerodynamic bodies: Shock Wave Boundary Layer Interaction (SWBLI), waveriders, lifting bodies, inlet and fuselage integration
- Propulsion technology: SCRamjet development (inlet geometry, fuel injection, ignition and combustion, materials)
- Materials and Thermal Protection Systems (TPS)
- Aerodynamically (autonomously) controlled gliding and self-propelled vehicles
- Real-time health monitoring

In order to develop the necessary technologies, there is a trend towards high-enthalpy flights, in which technologies for aerodynamic control, passive or active cooling and real-time health monitoring can be implemented for an extended flight time at low altitudes with hypersonic speed. Parabolic trajectories with launch elevations above 80 degrees are the established standard for most experimenters, but trajectories with low elevations, so-called suppressed trajectories can be performed as well. They allow for a longer experiment time in denser atmosphere layers at higher dynamic pressures. As an example, the DLR STORT project aims at speeds greater than Mach 8 at an altitude of about 50 km for an experiment time of more than two minutes (see Fig. 3-3). For re-entry experiments, velocities in excess of Mach 10 and defined vehicle pointing at atmospheric entry are achievable.

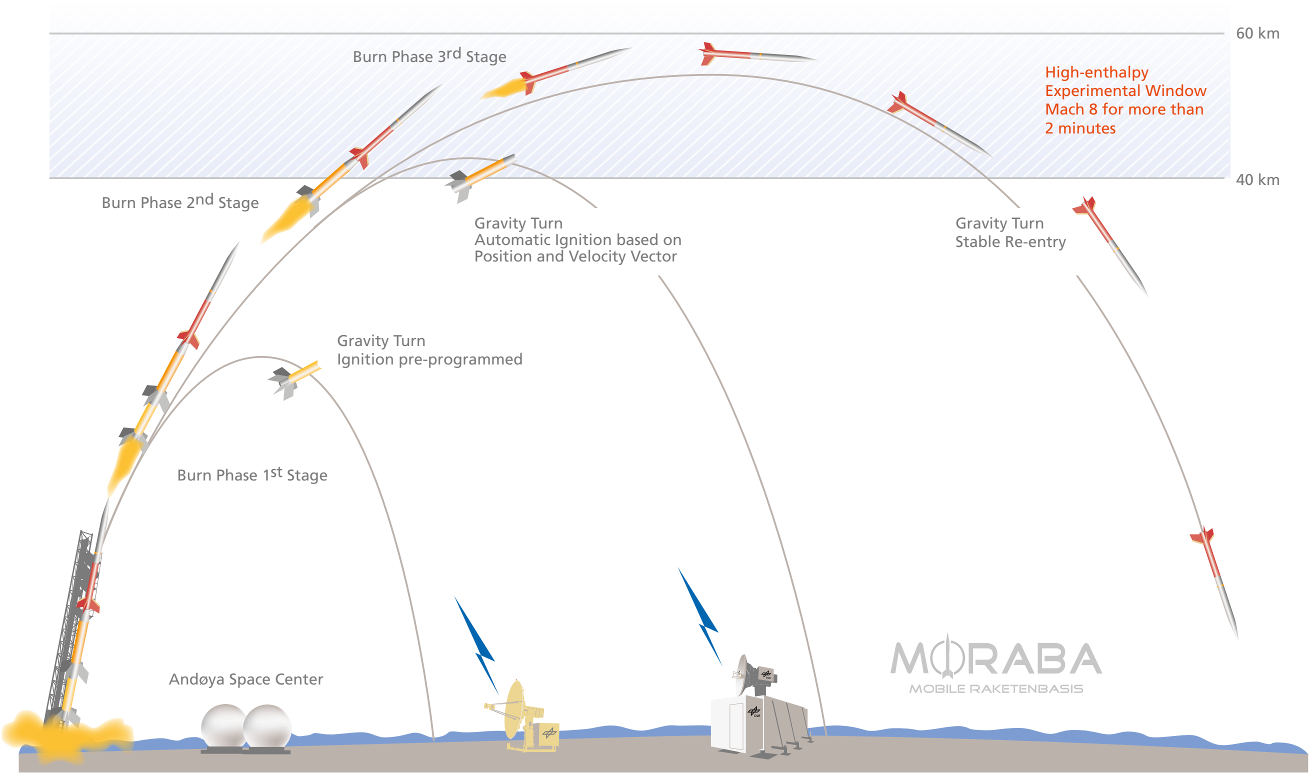


Fig. 3-3 Exemplary suppressed trajectory of a 3-staged vehicle with flight events

3.3 Atmospheric Physics Sensor Platform

Sounding rockets are the only platform that allows in-situ measurements within the atmosphere at altitudes above that of sounding balloons, which float at up to 40 km above mean sea level, and below that of satellites. Recently supported missions targeted altitudes between 100 km and 350 km.

Different sensor platforms are available consisting of a core structure that contains service and recovery system, as well as front and aft sensor decks which can be equipped with a multitude of different instrumentation. Scientists usually bring their own instrumentation which will be integrated at the sensor decks. Power supply, switching, data processing and transmission are coordinated by the service system provided by MORABA. Complementary measurements of position and orientation as well as acceleration and velocity may be performed and data provided to the scientists. MORABA is able to provide support for choosing and designing the instrumentation as well as integration and testing.

The sensor platforms can be mounted to different single- or two-staged carrier systems, depending on the performance and characteristics required to meet the scientific conditions. These sounding rockets are unguided, rail launched and consist of one or two solid propellant rocket motors, stabilized by three or four fins each and the payload with 356 mm diameter and an ogive nosecone with a spherically blunted tip. The fin incidence angle introduces a final vehicle spin of more than 3 Hz. This reduces impact dispersion and supports the scientific measurements.

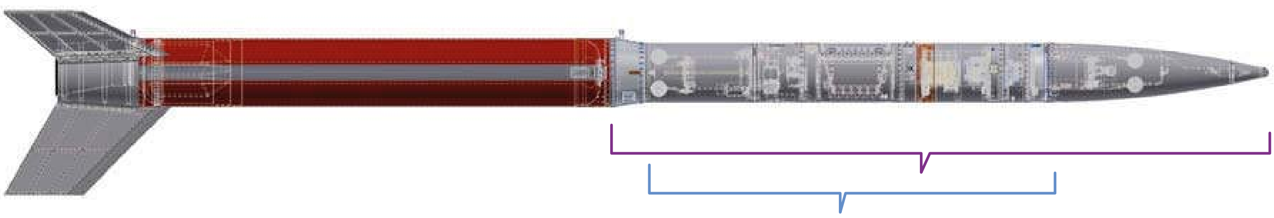


Fig. 3-4 Exemplary Single-staged vehicle overview with payload (purple) including sensor platform (blue).

Figure 3-6 shows a plan-view of the PMWE2 sensors and their integration on each experiment deck. Different sensors and their configurations have been used compared to PMWE1.

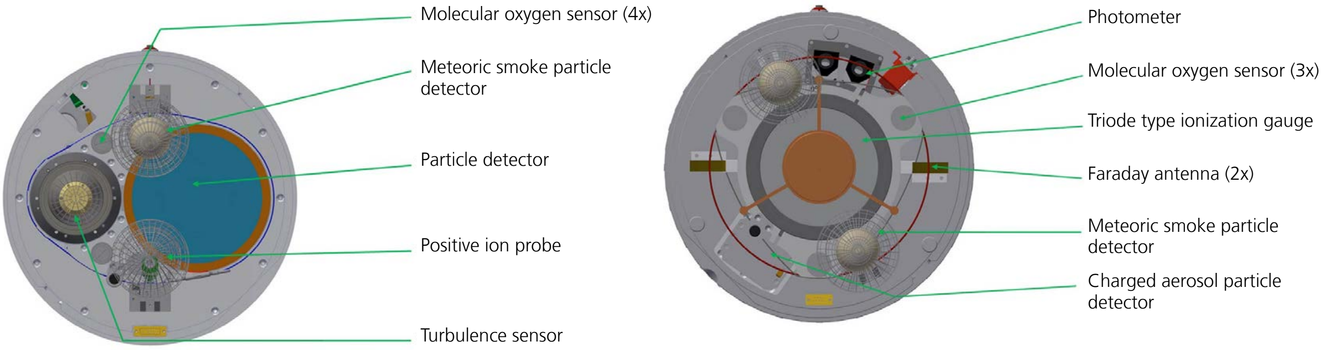


Fig. 3-6 PMWE2 Experiments Top Deck (left) and Aft Deck (right)

Typically, measurements are performed between 60 and 100 km during the ascent and descent phase. There is also a possibility to eject free-falling units at any time after the thrusting phase and above the denser atmosphere, e.g. at apogee. Recovery of the sensor platforms is possible over land and sea, depending on the launch site. Simultaneous ground-based radar- or lidar-measurements are often arranged and can be coordinated by the launch range.

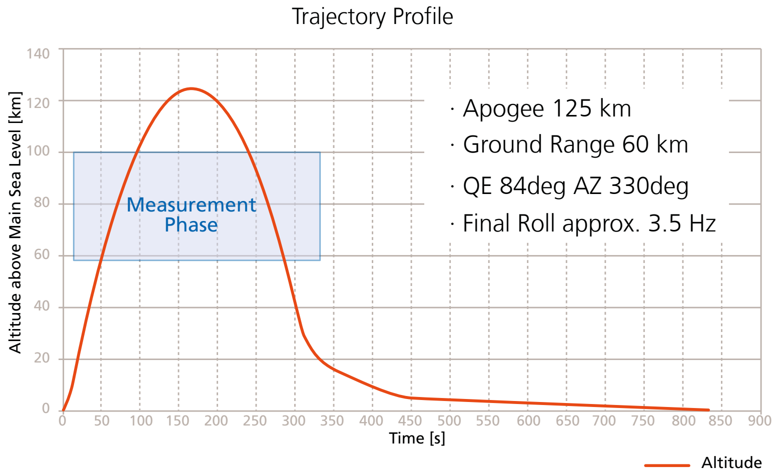
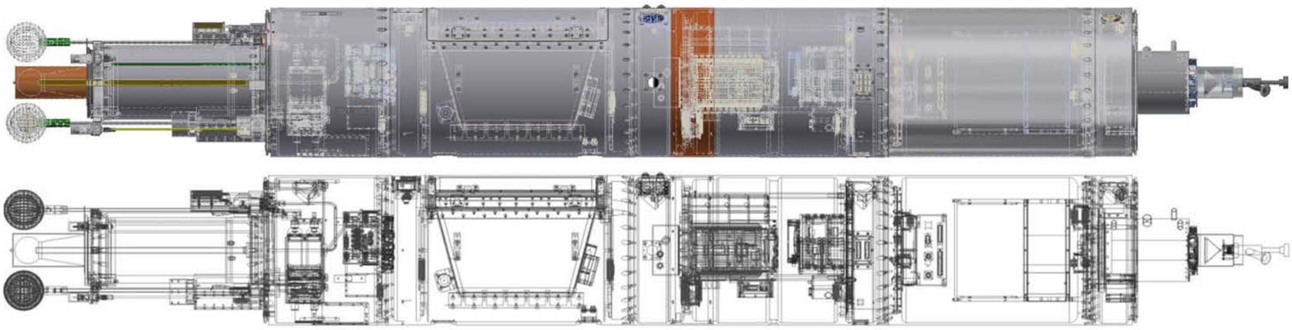


Fig. 3-5 Typical Trajectory of an Atmospheric Physics Mission

The sensor platforms are part of the payload with a total length of ca. 4 m and a lift-off mass of approximately 235 kg. After separation of the rocket motor during the ascent phase, the sensors of the aft deck can perform measurements. After leaving the atmosphere, the nosecone is ejected and the front deck sensors are ready.

Typical instrumentation provided by the scientists contains:
- Mass spectrometers
- Particle detectors
- Positive ion probes
- Electron probes
- Atomic and molecular oxygen sensors
- Turbulence sensors
- Photometers

An example for the configuration of different sensors and their integration is shown for the PMWE1 platform (see Fig. 3-7). Transfer Frames: Bit rates: between 5 and 8 mBit/sec



	CONE, Fipex, Faraday Ant, ION Probe, MSPD, Faraday Cup, PAT	Seperation Module	Recovery System	Service Module	ROMARA + Adapter-ring + Spin Balance Mass	Fwd ROMARA	
L	597mm	296 mm	582 mm	606 mm	591 mm	361 mm	Total lges = 3033 mm
m	-	33.5 kg Sep. module + Exp.	37.8 kg	40.6 kg	48.2 kg ROMARA + Adaptering	-	

Fig. 3-7 Measurement and recovery configuration of PMWE1. Mechanical drawings (above) and characteristics (below) of the different modules.

Recovery systems for sea and land recovery of the payload can be provided by MORABA (see **section 6.2**). If desired, a Free-Falling Unit (FFU) can be ejected from the aft end of the sensor platform.

The ejection mechanism was developed for the MSMA experiment, a free-falling football sized sphere developed by ARGUS Electronic and the Leibniz Institute of Atmospheric Physics (IAP). It was equipped with accelerometers, gyroscopes, a magnetometer, a GPS as well as a bidirectional telemetry module and performed density, temperature and horizontal wind measurements in the middle atmosphere.

The mechanism concept offers a fully mechanical and passive experiment release as there is no active release sequence. The ejection unit mainly consists of three ejection tracks and an experiment canister (see Fig. 3-8).

The tracks are mounted to the 14´´ Radax/Manacle adapter and the rocket motor adapter. The experiment canister houses the FFU and is guided by the tracks. Separation of the main payload from the rocket motor triggers the ejection. The canister is then lifted by three preloaded springs and opens automatically at the top-level position. The FFU is horizontally pushed out by flat springs. The lateral ejection vector prevents collisions with the main payload.

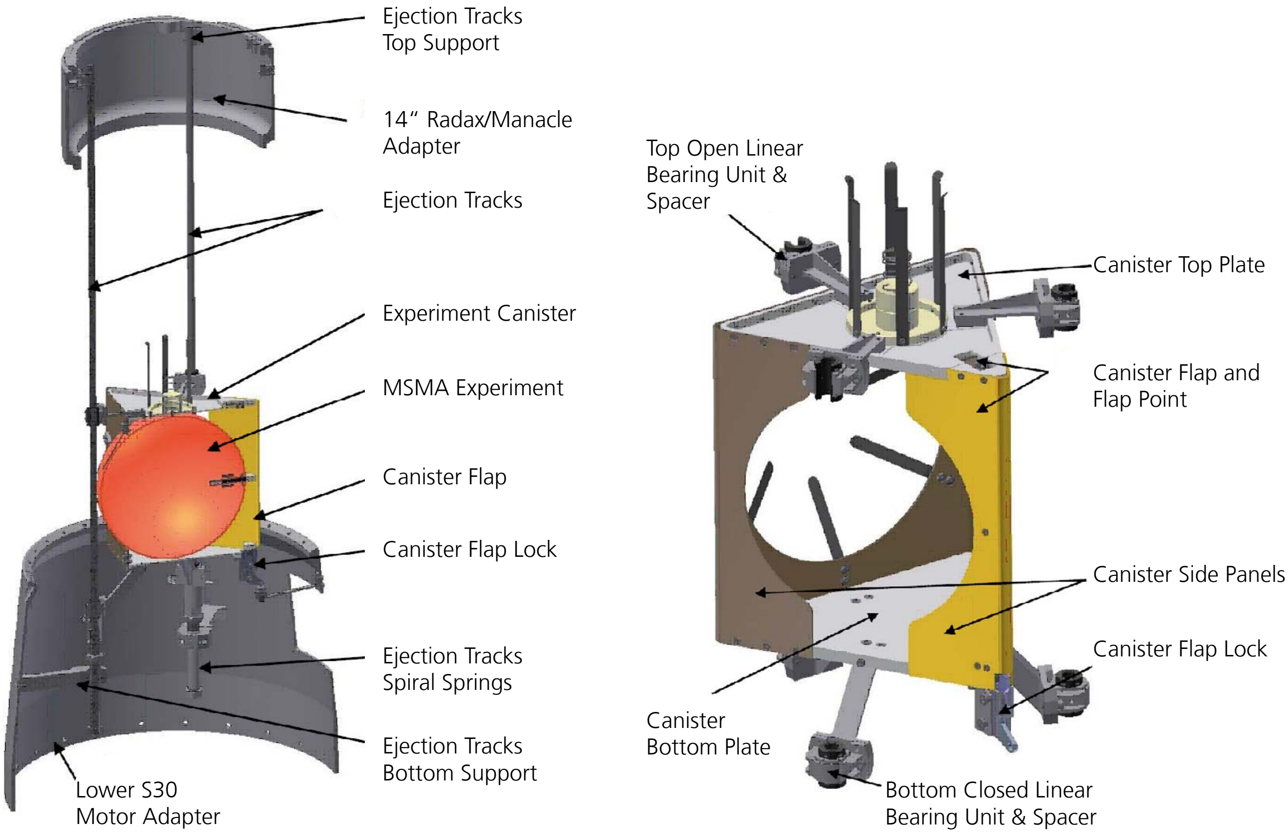


Fig. 3-8 Free falling unit ejection mechanism (left) and detailed view of experiment canister (right)

3.4 Technology Testing Platform

Sounding rockets as an experimental platform in technology development provide an excellent opportunity for the testing of technologies and applications for space-related developments. The sounding rocket platform thereby provides the basis of the experiment in the sense that it delivers the scientific payload to the desired experimental conditions. The latter can be a certain aerodynamic condition for hypersonic and re-usabiliy research, or minimized residual movements of the payload for µ*g* research or that the payload points to earth´s nadir in order to let gravity act in the direction of the measurement device, e.g. for matter wave interferometry. The sounding rocket platform can thus act as a flying wind tunnel, as a long duration drop tower as well as a preparatory "first stage" for the testing of upper stage technology, such as propellant handling. The employed subsystems in each application are adapted for the specific mission, but not fundamentally different. Technology that was developed for one research area can be adapted for other areas. This enables new research fields to be unlocked for exploration with the help of cost-efficient sounding rockets. For example, attitude control, that was developed for fundamental research in astrophysics, allowed completely new applications for hypersonic and µ*g* testing. The boundaries between fundamental research and technology testing and between new and old applications are therefore fluid and not easily identified.

Some exemplary topics and applications for technology testing from recent MORABA missions are
- Space Access Launcher Technology
- Reusability Technology Testing
- Fundamental Flow Physics

Space Access Launcher Technology

Space Access launcher technology development is actively being supported by direct technology testing such as during the Cryofenix project. Liquid propellant handling experimentation under weightless conditions was supported with controlled moderate linear acceleration. Residual accelerations of less than 10-5 g can generally be achieved during the baseline free-fall part of the mission.
The linear acceleration module was a derivative of the rate control systems that are used on all microgravity missions and could be further extended for instance to induce lateral movements for the investigation of sloshing behavior during free-fall. Readily available cold-gas thrusters with impulse control can deliver up to 100 N each and can be bundled if necessary. Accurate rate and attitude data can be provided and attitude can be measured and controlled.

Reusability Technology Testing

The recently developed project ReFEx will make use of a sounding rocket platform to bring its lifting body vehicle to flight conditions resembling those that would be experienced by a potential reusable first stage of an access to space system. The sounding rocket is unguided and the entire vehicle is scaled to small size for this type of research, with the payload mass being less than 600 kg. This payload shall be brought on a "flattened" trajectory with an apogee of less than 85 km. This is achieved by a prolonged coast phase after first stage burn-out and before second stage ignition, resulting in a significant gravity turn of the free-flying second stage and payload. The planned delivery point provides the experiment with a Mach number of 5.5 at an altitude of 75 km.
The ReFEx project thus employs cost effective sounding rockets to conduct a highly complex experiment. The sounding rocket platform's abilities will be yet expanded to shallow trajectories with the associated thermal protection systems. The approach should ultimately allow the regular conduct of low-cost experiments to expand knowledge of high to low speed aerodynamic control of lifting body vehicles.

Fundamental Flow Physics

The investigation of fundamental physics within high speed flows is a critical technology for any planetary entry, earth re-entry or space access system. The present uncertainties in flow properties at high speed result in increased thermal protection mass and hence reduced payload capacity. While simple parabolic trajectories on sounding rockets have been demonstrated regularly, the Mach 10 flight of the SHEFEX II mission has taken this further. The second stage was reoriented prior to ignition, allowing the trajectory to be shallower than previously flown by MORABA. This resulted in a prolonged travelling time through the dense atmosphere at high speeds, for the evaluation of facetted thermal protection systems as well as aerodynamic control strategies. The more recent flight of ROTEX-T has simplified flight testing by storing very high data rates onboard without the need to transmit high bandwidth telemetry data to ground. Further, complex and costly reorientation systems to align the body axis with the flight vector were omitted for simplicity of the mission and higher flight velocities, yet resulting in valuable high-speed data at more than Mach 5. The experimental body impacted in the Esrange Space Center impact area after separation from the stabilizing aft end and was successfully recovered. Such approaches to high speed flight testing open the opportunity to gather large amounts of high-speed flow data at low cost.

Platform as the Experiment

In some cases, the sounding rocket platform itself becomes part of or the main experiment. The ATEK project made the second stage rocket motor an experiment where composite fins and thermal protection systems were tested in flight in a highly demanding high temperature and high-density abrasive particle loaded flow of a composite solid propellant rocket motor.

3.5 Student Platforms

The REXUS/BEXUS (Rocket/Balloon Experiments for University Students) program allows students from universities and higher education colleges across Europe to carry out scientific and technological experiments on research rockets and balloons. The idea is that the students experience a full project cycle from application for funding through selection process, design and review, assembly integration and test through to flight on a sounding rocket. A detailed description on the REXUS platform with all technical interfaces can be found in the REXUS user manual: **http://rexusbexus.net/rexus/rexus-user-manual/**

4. Launch Missions and Operations

With all required equipment being mobile (including Launcher, Telemetry and RADAR stations), MORABA has the capability to conduct a sounding rocket launch from any place on Earth that provides the required access by road or air transport and a minimum of building infrastructure. However, Instrumented Ranges around the world offer quicker, more cost efficient and flexible conduct of missions. Hence, MORABA conducts the vast majority of its missions at one of the partnering ranges.
ESRANGE Space Center in Northern Sweden and Andøya Space Center in Northern Norway are by far the most often visited Ranges due to their easy accessibility, outstanding partnership and performance. The European Range Network within the EASP (Esrange Andøya Special Projects Agreement), allows scientists of five ESA member states facilitated access to the European rocket ranges ESRANGE and Andøya Space Center. The EASP member states France, Germany, Switzerland, Norway and Sweden finance the running of the sounding rocket and stratospheric balloon facilities. Furthermore, launches have been performed from Australia and Brazil in recent years.

In the intent to allow the customers to focus on their experiment, MORABA often takes full responsibility of mission preparation and launch operations. In particular, MORABA acts as the interface between the customer/scientist and affected authorities and launch ranges for the following topics:
- Range contracting
- Range and Flight Safety approvals
- Transports and export control issues
- Interface Control Documents, Flight Requirements Plan
- Accommodation on the Range
- Medical attendance during the mission
- Mission Lead
- Countdown Planning

The mission preparation phase runs in parallel to the manufacture, assembly and testing of the payload and vehicle subsystems. MORABA actively initiates and accompanies the individual tasks to provide guidance to the customers and ensure a seamless progress in the project.

Depending on the customer and vehicle requirements, MORABA frequently supports mission operations such as:
- Vehicle and Payload Assembly
- Bench and Flight Simulation Testing
- Vehicle Roll Out to Launcher
- Launcher Operations
  - Accommodation of Ground Support Systems in the Launcher
  - Umbilical Rigging
  - Arming/Disarming
  - Late Access of Experiments
  - Countdown Operations
- Telemetry, Tracking and Control
- Vehicle Wind Weighting and Flight Safety
- Payload and vehicle communications
- Flight Simulation and Test Countdowns
- Flight Control
- Recovery water & land
- Postflight analyses

The launch of a sounding rocket commonly requires a larger number of teams and people with different backgrounds to work together in confined space and schedule. MORABAs professional experience ensures an efficient conduct of the flight mission in close cooperation of all project partners.

5. Sounding Rocket Launch Vehicles and Rocket Hardware

5.1 Launch Vehicles and their performance

The research vehicles offered by MORABA have been used by a wide spectrum of payloads that featured a variety of mass, complexity and transport requirements. In order to address the requirements of all payloads, MORABA relies on a large portfolio of rocket motors which can be flown in single stage as well as stacked configurations. MORABA constantly strives to enhance the selection of active rocket motors in order to improve its flight capacities or replace systems that run out of service. Although the developments in liquid, gelled and hybrid propulsion are closely followed, the comparatively high power density, operational simplicity and safety of solid rocket motors have led to their exclusive use by MORABA so far.
A large portion of the active portfolio consists of rocket motors with military heritage. These motors are transferred to MORABA or its partners from governments that tear down a fraction of their armory. As these motors have usually exceeded their shelf life, inspection and re-lifing efforts become necessary. Many successful missions prove the flight worthiness of these motors which are not least attractive due to their competitive cost structure.
The second group of the portfolio is made up by motors available from third parties. A longstanding cooperation with the Brazilian Department of Aerospace Science and Technology (DCTA) has led to frequent and continued use of its S31 and S30 rocket motor stages. Currently, MORABA is also developing a solid motor stage with Bayern Chemie GmbH and acquiring some units of Magellan's Black Brant V.
While the majority of payloads served put 70-500 kg on the scales, MORABA has also launched heavier ones and currently designs missions involving payloads up to 2 to. The vehicle to accommodate such masses is developed in cooperation with DCTA.
To minimize the launch cost, passive stabilization and separation systems are implemented where ever possible. However, if requirements regarding impact dispersion or trajectory insertion accuracy necessitate trajectory control, MORABA can implement cold gas attitude and thrust vector control systems.
Figure 5-1 illustrates significant members of MORABA's current rocket family.

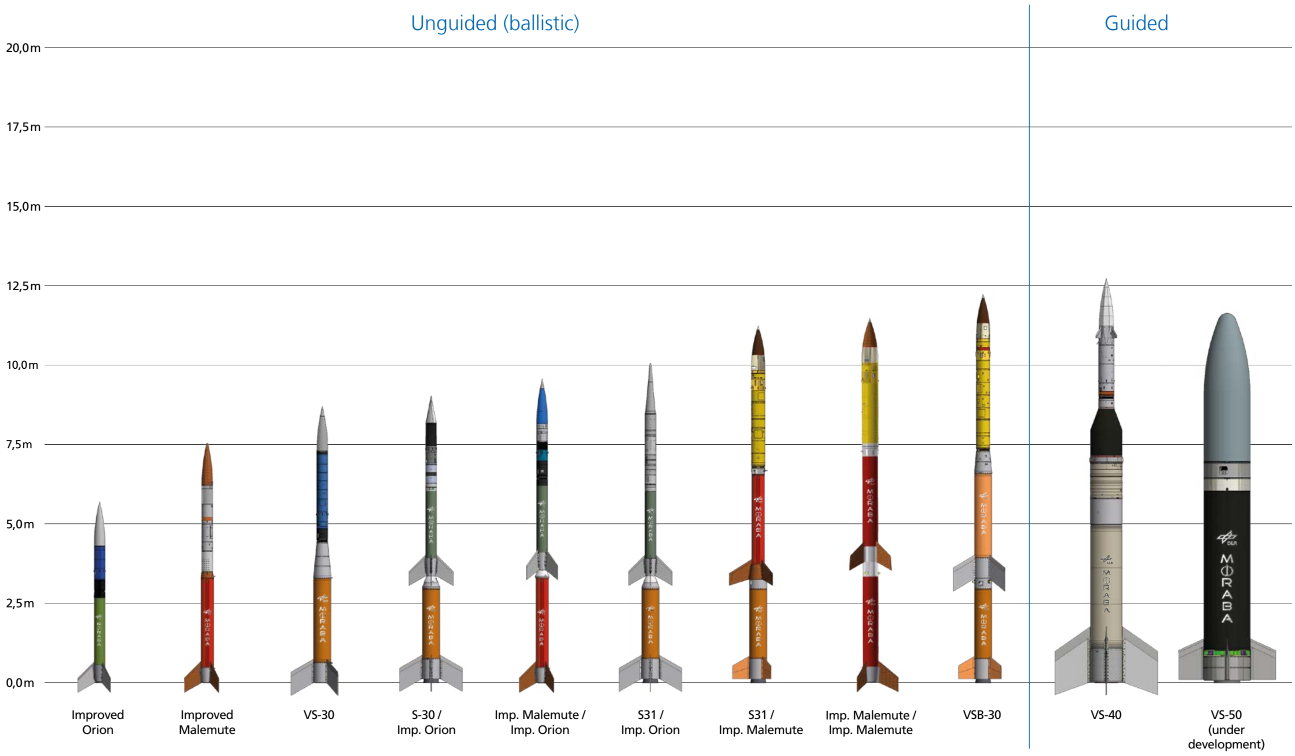


Fig. 5-1 MORABA Sounding Rocket Portfolio. The VS-40 is currently not available. The VS-50 is in development Phase D.

The graphs below and the following subsections detail out the apogee performance of MORABA's vehicles as function of payload mass. Hypersonics or re-entry research trajectories are also possible but not displayed here due to their diversity – the apogee performance is a good comparative measure for the performance of a vehicle to be launched onto a hypersonics research trajectory. To convert apogee performance into potential micro-gravity research duration, Figure 5-4 can be used.

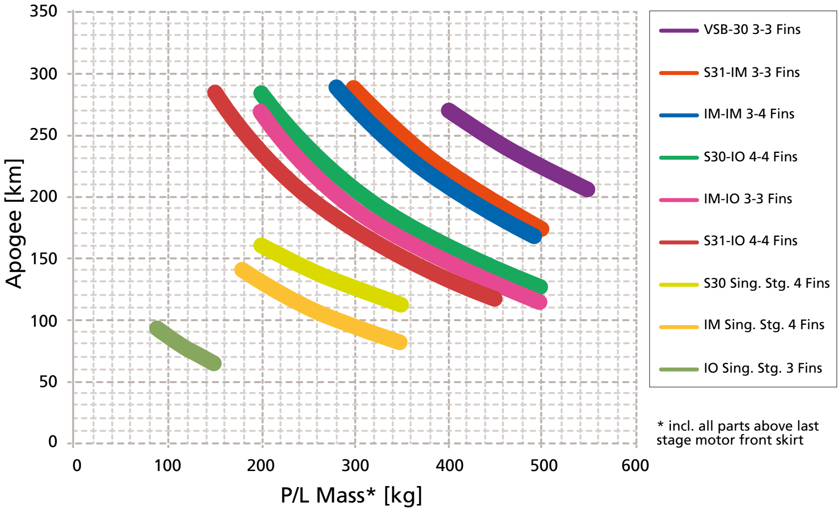


Fig. 5-2 MORABA Sounding Rocket Portfolio Performance (without VS-50)

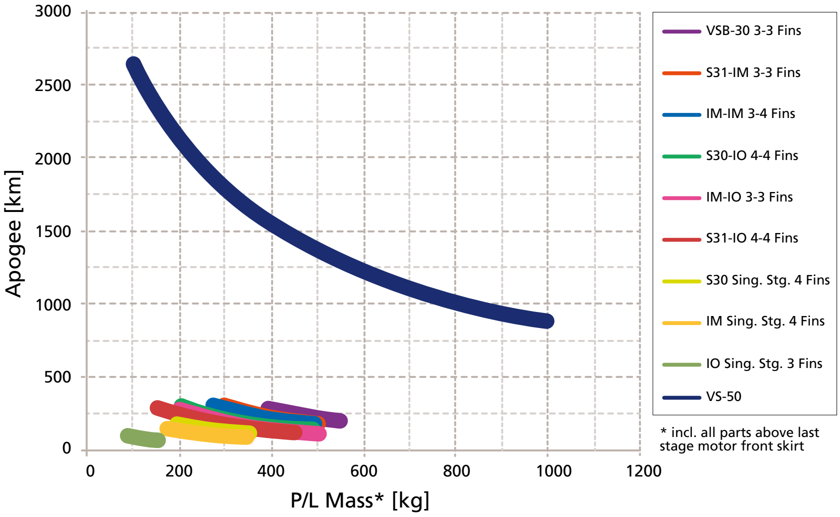


Fig. 5-3 MORABA Sounding Rocket Porfolio Performance (with VS-50)

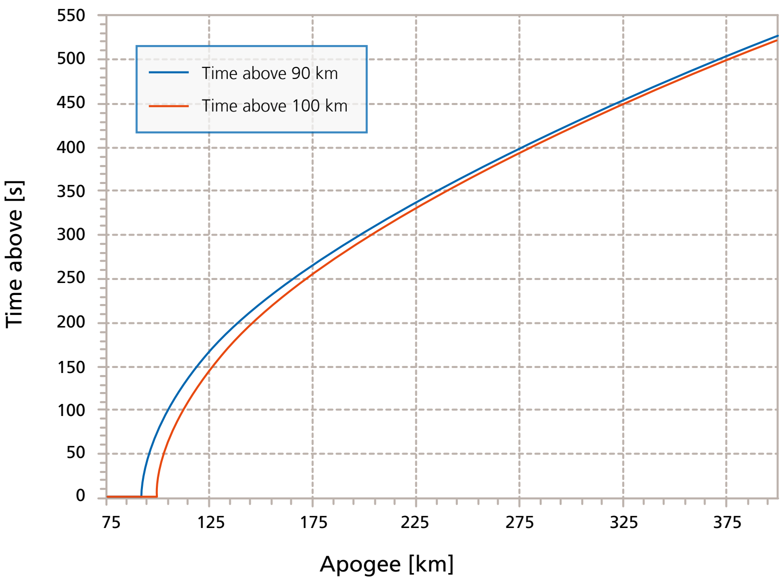


Fig. 5-4 Time spent above 90/100km versus Apogee

5.2 Rocket Hardware

The launch vehicle is probably one of the most prominent parts of a typical rocket. However, to perform a reliable flight, to use multiple stages or to offer the best possible scientific environment, several other components are required. These are developed by MORABA for each launch vehicle and manufactured. Hardware components of a typical sounding rocket cover

- Fin assembly
- Separation Systems
- Motor Adapter
- YoYo-Despin System
- Nosecones

Fin assembly

There are active and passive ways to compensate perturbation and ensure accurate and straight flight paths. The stabilizing fins are the most significant passive way, acting as aerodynamic surfaces to stabilize the rocket's flight. The aerodynamic forces acting on a fin create a moment that keeps the rocket in stable attitudes. Figure 5-5 shows an example of a sounding rocket consisting of three different stages with a fin assembly on each. Since a rocket is typically rotationally symmetric, fins always have to be placed in multiples. Typically, fins are used in a combination of three or four.

Fig. 5-5 STORT Vehicle, showing multiple stages with fins

Separation Systems

In order to use multiple rocket motors, the rockets are staged, as shown in Figure 5-5. Sometimes it is sufficient to stack the motors on top of each other. Sometimes, however, when higher loads have to be transferred, an alternative option is required. Further, the payload must be securely attached to the upper stage rocket motor and reliably released prior to experiment activation. Over the years MORABA has developed dedicated separation systems to carefully separate rocket motors and payloads. A typical separation system can securely attach the two parts and release them when required. In most cases an active separation mechanism accelerates the parts away from one another. A so-called manacle ring is torqued on a flange, clamping the two stages together. The Manacle ring can be opened through a pin which releases the locking mechanism and opens the ring. After the ring has been dropped, three plungers positioned circumferentially around the module are pneumatically driven outwards, separating the two adjacent stages. Figure 5-6 shows a separation system with an integrated YoYo-De-Spin system.

Fig. 5-6 Separation System with included YoYo-De-Spin. The flange on this module represents one side of the Manacle ring joint, whereas the round red actuators are the plungers that are pneumatically activated to separate the stages.

Motor Adapter

The motor adapter fulfills multiple functions. The most important function is often to house the ignition unit for the rocket motor that provides a timed current to initiate the firing. Another function can be the separation of the burnt-out motor which can be achieved the same way like the separation system. The equipment of the motor adapter, however, can change with the requirements of the different missions.

YoYo-De-Spin System

To reduce dispersion in the trajectory, the rockets are often spun up around the longitudinal axis. However, when e.g. microgravity has to be achieved, the spin has to be taken out again. In principle, the de-spin system is a steel wire wound up around the rocket body with two precisely calculated masses at the ends. Figure 5-6 shows a rendering of de-spin system used by MORABA. One of the two masses can be seen in the center of the image. When activated, the masses release and move outward through the centrifugal force and unwind the wire. Through conservation of momentum the rockets spin is reduced and if precisely calculated and built, the rocket is left without or with a little remaining spin. The residual spin can then be controlled by a cold gas system.

6. Data Handling and Payload Support Systems

6.1 Power and Information Supply

The experiment in the flight segment is provided with an interface that enables power supply and communication with the associated station in the user segment in both directions (downlink & uplink). The power supply can be used to operate the experiment and, if necessary, to charge the batteries installed in the experiment module. Communication is ensured in flight via radio link and on ground additionally via a wired connection, the umbilical. The Service Module (SM) is the central module of the flight segment where all Experiment Interfaces and experiment as well as housekeeping instrumentation converge and in which all devices and instruments for the provision of electrical and information technology services are housed.

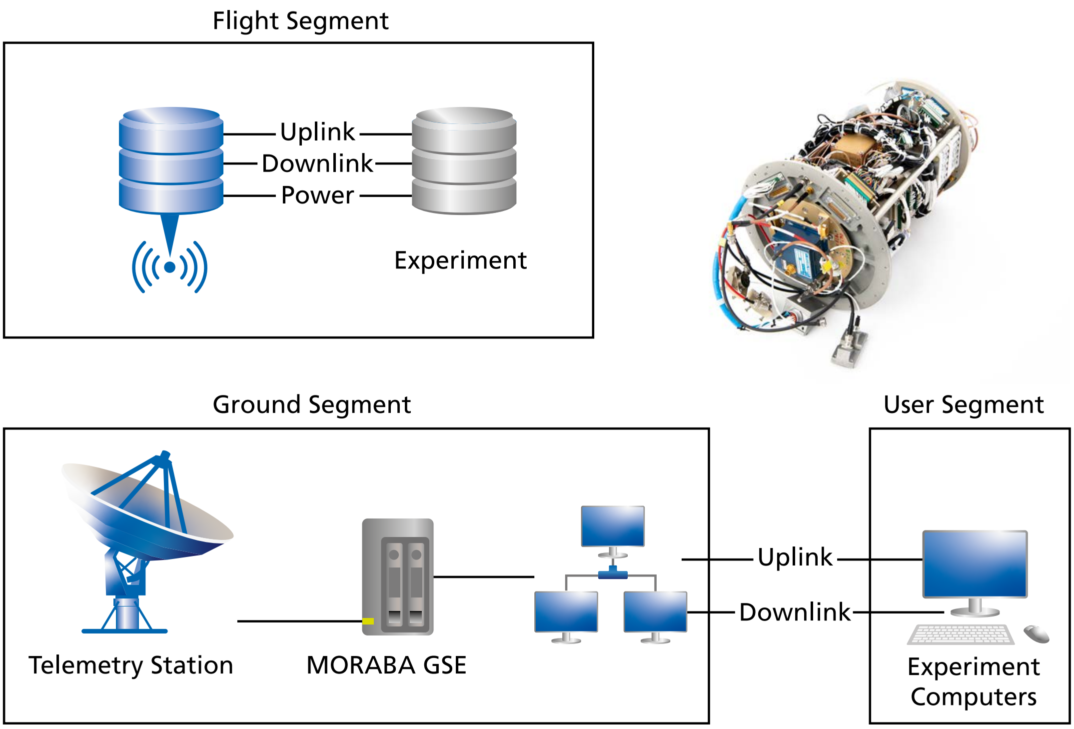


Fig. 6-1 Power and information supply and communication in different segments; top right: example of Service Module

6.2 Payload Support Systems

The Payload Support Systems are responsible for the communication on-board, communication between the ground stations and payload, collecting of scientific and housekeeping data, distribution of commands and real time information and the control of flight events. Furthermore, they fulfill the scientific requirements, like sensor or probe attitude alignment, establishment of microgravity environment and flight control. Additionally, payload support systems can supply experiments and scientific sensors with energy, control their activation period and their key parameters during flight. Finally, recovery systems for the scientific payload are required for many sounding rocket missions.

Payload Support Systems comprise
- Cold Gas Systems
- Rate Control Systems
- Attitude Control Systems / Precession Control
- Navigation and Sensor Systems
- Recovery Systems

Cold Gas Systems

Cold Gas Systems are used as actuators for introducing moments on the vehicle axes in order to perform attitude and rate control. The thrust levels to generate the moments are in the order between some tenth of 1 N up to 100 N. In most cases, gaseous Nitrogen is used to build up the necessary thrusts by the activation of a gas flow through nozzles.

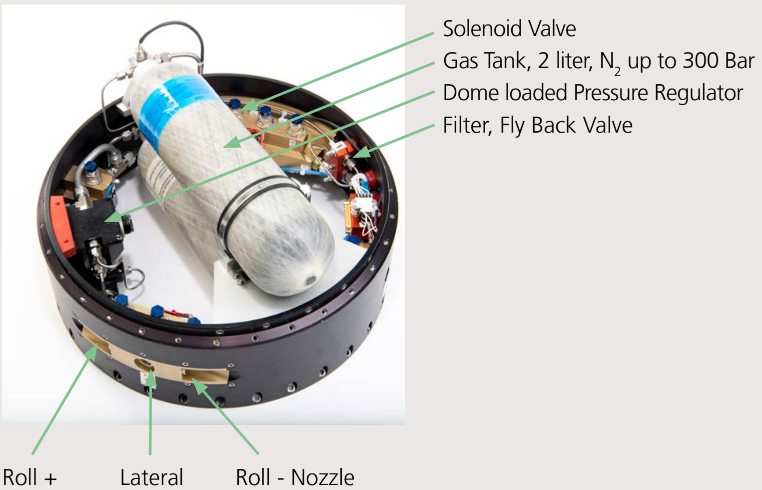


Fig. 6-2 Example of a 2-stage Cold Gas System (17″ cylindrical structure)

Cold Gas System principle key parameters are:
- 2-stage cold gas system
- Lower level defined by pressure regulator
- High level defined by the dome pressure
- Working pressure from 0.75-3 MPa
- Isp = 60-65 s
- Tank pressure up to 30 MPa Nitrogen

Rate Control Systems

Rate control systems, which are based on cold gas systems, are used for 2 typical applications:

- Reduction of the angular rates in order to eliminate the resulting centrifugal acceleration. This improves the quality of the microgravity environment for weightlessness missions.
- To reduce the oscillations (rate damping) of rockets or payloads during the re-entry into the atmosphere in order to support the passive aligning of the longitudinal axis to the velocity vector. This technique is mainly used for hypersonic research programs. The approach leads to a fast reduction of the angles of attack (AoA) and side slip, allowing undisturbed hypersonic flow research.

A cold gas system is mainly used to execute these tasks. It often consists of a gas reservoir, filled with N2 up to 30 MPa, a pressure regulator (one or two stage system), at least 6 valves and 8 nozzles. For the roll axis, 4 nozzles are used because of symmetry in order to reduce the impact on the lateral axes. In modern systems, adaptive control is implemented which improves the control parameters during the control sequences and adjust themselves to the physical properties.

Attitude Control System / Precession Control

Attitude control comprises the control of all 3 main axes. Typical applications are the pointing of sensors axes, the re-orientation of rocket stages prior their ignitions and the alignment of the longitudinal axis to the velocity vector. Precession Control is a special case of attitude control, whereby the rocket or payload rotates about its longitudinal axis with a higher spin rate, and a cold gas system tries to move the longitudinal axis to the desired attitude. At least one lateral nozzle (normal case 3 or 4) generates a thrust impulse and, therefore, a lateral moment, by pulsing at the right time and with the proper pulse duration. The main task of the control algorithms is to decouple the interferences between the lateral axes, which are determined by the Euler equations.

Navigation and Sensor Systems

Depending on the mission, different sensor packets are included to feed useful sensor data into the control systems. During microgravity missions, 3 axes rate gyros as sensors for delivering the inputs for the rate control systems are used. A separate, highly accurate and sensitive, 3 axes accelerometer packet measures the residual accelerations in all axes during the microgravity period and the acceleration during the ascent and descend phase.

For attitude control systems, more sophisticated sensors like IMU and GNSS sensors have to be used to deliver reliable data sets to the control systems. In order to increase the accuracy and reduce the drifts of IMU sensors' attitude and position data, online data fusion with GNSS data sets is necessary.

A MORABA standard navigation system consists of following components:

- DMARS-R (Inertial navigation system) acts as source for attitude data and source for position and velocity data
- Phoenix GNSS system acts as position and velocity data source
- Novatel GNSS system acts as position and velocity data source
- Data fusion will be used to improve accuracy

Recovery Systems

MORABA provides numerous flight proven recovery systems that can be customized for particular missions. The main reason for the usage of recovery systems is the retrieval of experimental probes, the retrieval of on-board data storage for high resolution data that cannot be transmitted by telemetry and the reuse of payload, platform and scientific instrument systems. Furthermore, the parachute recovery systems can be used as a flight termination system. MORABA provides land and sea recovery systems using multi-staged parachute systems.

Fig. 6-3 Land and sea recovery

For land recovery, payload masses up to 800 kg can be recovered; for sea recovery maximum payload masses of 180 kg have been successfully recovered to date. Typically, two-stage parachute systems are designed to decelerate payloads to comfortable landing velocities of less than 10 m/s. There are solutions for recovery systems at the front and aft end or in the middle of the payload.

Typical payload masses	70 – 800 kg
Typical payload lengths	2 – 6 m
Typical payload diameters	from 178 mm, 356 mm, 438 mm, up to 500 mm
Activation velocities	70 – 150 m/s

Table 6-1 MORABA Recovery Dimensions

Recovery systems include the parachutes, housekeeping and safety electronics, activation electronics and mechanics, video cameras as well as tracking systems (FM Beacon, GPS/Iridium).

7. Environmental Testing and Test Infrastructure

MORABA has access to various test facilities for different subsystem and system tests to be performed in preparation of a launch campaign. The test infrastructure is partly located in-house or can be used in partner laboratories on a contractual basis. The in-house laboratory includes 3-D air bearing tables as well as a thermal vacuum chamber.

Environmental tests are performed in order to verify the structural integrity as well as functionality and therefore the flight worthiness of individual sounding rocket vehicle components, flight experiments as well as complete payload stacks under worst case environmental conditions. In the field of aerospace engineering, such testing typically comprises thermal, vacuum, vibration and static load test runs on either qualification or acceptance level. DLR's MORABA not only conducts and supports, but is also responsible for the test activities.

Since MORABA does not operate its own facilities for vibration and static load tests, it is hiring the needed test bed including the operator personal. However, the test planning, setup, performance and interpretation of results is under full authority and responsibility of the respective MORABA personnel. Over decades, MORABA has formed a unique network of DLR internal as well as external contacts to a large variety of test.

Thermal and Vacuum Testing

To verify the characteristics and behavior in space environment, a system must often undergo extensive thermal and vacuum testing during the verification process. Unlike mechanical tests which mainly test the behavior during the launch phase, thermal and vacuum tests concentrate more or less on the qualification/acceptance for the operational phase in space. Vacuum testing is not only applicable for systems being operated under vacuum conditions, but also for the verification for those systems (mainly electrical), e.g. performing in the absence of convective cooling or corona effects for high voltage systems (U > 40 V).

Fig. 7-1 MORABA thermal vacuum chamber

Operating Range:	
Vacuum	
1) Fine vacuum	10^5 Pa to $5*10^{-1\ Pa}$
2) High vacuum	$5*10^{-1}$ Pa to 10^4 Pa
Temperature	-70°C to 80°C (the upper limit is controlles by SR 601)
Dimensions:	
A circular copper plate with a pattern of threaded holes M6 is provided as base for the test setup in the TVC. The plate may be temperature controlled. The diameter of the plate is 1300 mm. The available volume inside the bell of the chamber is cylindrical with dimensions:	
Diameter:	1350mm
Cylindrical height:	1400mm

Table 7-1 Performance data of MORABA thermal vacuum chamber

Vibration Testing

During vibration testing, the dynamic behavior of individual sounding rocket vehicle components, flight experiments as well as complete payload stacks is tested. In general, vibration tests consist of sine and random loading as well as Eigenfrequency search runs, which are typically performed in all body axes of interest. Each sine and random test run has to be embedded in a sine search run before and after testing, where the relevant Eigenfrequencies of the test setup have to be identified and evaluated. This allows the prediction of possible resonance cases as well as the identification of damages and changes in the test setup's mechanical behavior.

Fig. 7-2 Vibration test run of complete payload (left) and single experiment deck (right)

Static Load Testing

In some cases, mainly for qualification reasons of mechanical systems, primary and secondary structures need to undergo an additional static load test. Those tests can be on coupon, subcomponent or large component level such as payload bending tests (large component test), fin bending test (sub component test) and tensile tests for crimped cable terminals or manufacturing samples for quality reasons (coupon level).

Verification of Control Loops which are based on Cold Gas Systems

All control loops for Cold Gas Systems must be tested and verified by software evaluation tools and by air bearing tests as shown in Fig. 7-3. As the sphere in the center of the mock-up turns on an air bearing with minimal friction, similar rotational environments as in space can be established. The mock-up has to be equipped with the adequate sensors and a telemetry system to allow the online verification, and sometime commanding of the tests. Similar ground equipment to that of a launch mission has to be used to receive the RF signals, which are sent during the air bearing test. The sent data are decoded and distributed to computers for quick lock and storage capability. After each simulation run, the data has to be analyzed in order to verify the results of the control loop sequence.

Fig. 7-3 3-D air bearing test for the verification of Cold Gas System control loops

8. Mobile Launch and Range Infrastructure

The mobile infrastructure of MORABA allows the worldwide setup and support of sounding rocket, balloon and satellite missions. Already 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, such as extreme temperatures or salt water.
Detailed technical information on the mobile Telemetry Station, the Radar Station as well as the mobile Launcher can be found in the document **"MORABA Mobile Launch and Range Infrastructure".**

Fig. 8-1 MORABA owns mobile TT&C stations as well as a mobile launcher for launch missions all over the world.