OHB-SYSTEM ACTIVITIES IN ESA MARS PROGRAMMES

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Summary

The general objective of ESA's Mars Robotic Exploration Preparatory (MREP) Programme is the exploration of Mars with Mars Sample Return (MSR) as long term goal to be achieved in the 2020's (ESA Robotic Exploration Technology Plan, Nov 2010). MSR is a complex multi-segment mission and currently the mission architecture and the mission schedule definition is on-going. Possible intermediate missions are envisaged and prepared also to support the MSR scenario definition. ESA has defined five candidate missions for down-selection before the next ESA council on ministerial level (ESA Robotic Exploration Technology Plan, Nov 2010).
For two of these missions industrial assessment studies have been initiated. Those two studies are called Mars Sample Return Orbiter and Mars Precision Lander. For both studies two parallel contracts have been awarded to industrial consortia. The studies are funded jointly by ESA's GSP (General Studies Programme) and MREP Programme. All four studies awarded to industry are running until the end of the year 2011.
OHB System is part of the TAS-I consortium for the Mars Precision Lander mission study, responsible for the Carrier and part of the TAS-F consortium for the Mars Sample Return Orbiter mission study taking care of mechanical, thermal and propulsion subsystems.

The objective of the Mars Sample Return Orbiter mission is to:

- provide telecommunication capability (monitoring of entry, descent and landing for MPL)
- detect, capture and bio-seal an Orbiting Sample (launched into Martian orbit by a Mars Ascent Vehicle, which is not part of the study)
- return the sample to Earth
- provide safe re-entry through Earth atmosphere in a capsule

The envisaged primary launch date for this mission is 2022 with back-ups in 2024 and 2026.

The objective of the Mars Precision Lander is to safely deliver a sampling and/or fetching rover to the Martian surface in 2022 – 2026 timeframe at a landing precision better than 10 km. After launch from Earth the spacecraft composite arrives at Mars, where the MPL will be separated from the Carrier and descends through the Martian atmosphere. After touch-down the Rover will be deployed.

For both missions the MSR-O is foreseen to monitor the entry, descent and landing phase.

The paper will give an overview about OHB System past and present Mars related activities as well as an overview over the two mission studies MPL and MSR-O.

1. OHB SYSTEM MARS ACTIVITIES

OHB System AG has been working on Mars activities since long term and has gained experience on a broad variety of tasks within phase 0/A and B studies. With the ExoMars mission OHB System is currently also participating in an implementation phase responsible for the mechanical, thermal and propulsion subsystems of the ExoMars orbiter to be launched in 2016.

A more detailed overview on Mars activities and the various tasks OHB System has performed is given in the following.

NetLander was planned as a Mars Mission to perform research of the interior of the planet and its atmosphere. Each one of the four identical landers should be equipped with science payloads dedicated to study the atmosphere and geosphere of Mars. Operating together or stand-alone once landed on the Martian surface, they were supposed to investigate meteorology, ionosphere, surface and subsurface. Landing locations spread over two hemispheres and a mission duration of one Martian year exposes the surface modules and its sensitive electronics compartment to a wide range of hostile conditions.

The German section of the program consisted of the responsibility for the structural and thermal design of the Surface Module Electronic Compartment (SEC).

This task was jointly performed by OHB System, the Institute for Planetology of the university of Münster and DLR-Braunschweig.

OHB System's responsibility was the thermal design, analysis, manufacturing and test of the SEC. The purpose of the thermal control system was to maintain the electronics and battery temperatures within a narrow band, during transfer to Mars as well as during surface operations. Contradicting demands of reduced heat leaks and effective dump of surplus heat required new technologies and advanced design concepts to be satisfied under strict mass limits imposed. The responsibility of OHB for the thermal control system consisted of the following:

- Thermal concept for the electronics system
- Thermal analyses
- Development & field testing of a highly efficient insulation system in conjunction with closed thermal transport system

A breadboard of the complete SEC-structure and thermal subsystem has been manufactured and the compliance to the requirements successfully demonstrated in a planetary simulation chamber of DLR Cologne in 2003. Phase B of the project was successfully concluded end of 2003. After that, the program was decommissioned by the project management.

EVD (Earth Vehicle Demonstrator) was a proposal for an ESA’s Aurora arrow mission aiming at demonstrating key technologies in preparation of the Mars Sample Return mission. High-speed re-entry through the Earth’s atmosphere is necessary in the future Mars Sample Return mission, which will be done by an Earth Return Capsule. OHB-System was responsible within the ESA industrial EVD Pre-Phase A study led by EADS-Astrium for mission analysis and launcher options, the trade-offs and design assessment of the Carrier (transporting the entry technology demonstrator) and proposal of flight technique measurements necessary for a demonstration mission. The responsibility included requirements analysis as well as design and engineering of the Carrier and its interfaces. Mission analysis tasks covered included mission design, overall scenario optimisation, landing site trade-offs, trajectory definition and optimisation, launch scenario optimisation including launcher selection, Earth entry dispersion analysis, etc. The Pre-Phase-A study contract was finished in April 2005.

ESA’s **ExoMars** is an Aurora flagship mission. Its aim is to further characterise the biological environment on Mars in preparation for robotic missions and then human exploration. Data from the mission will also provide invaluable input for broader studies of exobiology - the search for life on other planets.

OHB is co-prime to TAS for the development of the carrier (Phase A/B1 successfully finished), which will be transporting the landing module to Mars, as well as prime for the orbiter for receiving data and forwarding it to Earth. The implementation phase is planned as a collaborative effort and presently in negotiations between ESA and NASA.

OHB-System has designed in phase A the Descent Module including the Entry Descent and Landing sequence and systems in the ALENIA team (now TAS-I). A trade-off of different landing methods was performed, including the vented Airbag and non-vented bouncing Airbag concept. Also the possible additional use of an inflated heat shield as landing airbag for mass saving was investigated. For this a dynamic impact analysis sequence was performed. The outcome saw the conventional bouncing airbag revealed to be the best suited concept.

In the second phase of the ExoMars program, OHB System has detailed the design of the descent module (DM). Airbag positions and folding schemes were defined. Retro rocket types were selected and accommodated. A structure shape trade-off and opening sequence analysis was performed. For stabilization a parachute system is integrated into the frame of a spin-eject devices.

OHB System also did mission analysis for ExoMars within ESA industrial Phase A/B1 study. Tasks covered included among others launch scenario optimisation, interplanetary transfer optimisation, Mars orbit selection, Mars arrival optimisation, Mars entry dispersion analysis, ranges and angles calculation, ground station analysis, orbiter / lander / rover visibility, etc.

Later in Phase B1, OHB System took the co-prime responsibility for the ExoMars Carrier as well as the prime responsibility on an independent European Mars orbiter providing data relay capabilities for the ExoMars Rover. However, the European Mars orbiter has been removed from the ExoMars mission after Phase B1 as result of budgetary limitation on mission level.

The project is now in the extended Phase B2 with launch scheduled for 2016. In the ongoing project phase OHB System is (as a co-prime) responsible for the complete structure, thermal and propulsion subsystems of the Carrier / Orbiter. This role includes the complete design and development of these three subsystems at system and subsystem level, the specification on component level, the manufacturing respectively procurement of all components of these subsystems as well as the integration and test and launch campaign support.

ESA has started in spring 2008 two parallel Phase A studies called “**NEXT Mars Orbiter with network science and RVD-demonstration**”. These studies have to be seen in the context of preparing new capabilities and technologies as relevant for a Mars Sample Return mission, as explained before.

Therefore, the Next-Mars mission under investigation in 2008/2009 was aiming at demonstrating aerobraking as well as rendezvous and capture in Mars orbit, and delivering a network of scientific surface stations. It was planned for launch by a Soyuz 2.1b vehicle from Kourou within a launch window in 2015-2016 with a back-up date in 2017-2018.

On its hyperbolic approach to Mars, the spacecraft would have deployed sequentially a number of probes that should enter into the atmosphere and descent and land by means of parachutes and airbags. These mission capabilities are highly relevant for a Mars Sample Return mission. It has been studied in detail with OHB System as subcontractor to TAS in the Phase A2 study. In the Next Mars Orbiter study, OHB-System was responsible for the complete mission analysis, starting from the separation of the spacecraft from the launch vehicle until reaching the final operational Mars orbit. This task included the detailed analysis and trade-offs of various launch and interplanetary transfer options, Mars arrival optimization, atmospheric entry analysis, aerobraking analysis, orbit selection, lander visibility and ground station visibility analysis, etc., making use of a variety of highly-sophisticated tools for mission simulation and trajectory optimization.

Further work on the preparation of the Mars Sample Return mission OHB System has performed within the ESA's **MSR Precursor Mission M1 Pre-Phase A** study which is a precursor mission to Mars in preparation of the MSR Aurora flagship mission. Within ESA's industrial Pre-Phase A study covered by the MSR Phase A2 contract OHB performed the Mission analysis. Tasks included among others the launch scenario optimisation from GTO, interplanetary transfer optimisation for several transfer options, Mars arrival optimisation, aerobraking analysis, ranges and angles calculation, ground station analysis, orbiter / lander visibility.

Summarizing OHB System has gained a high amount of experience for Mars missions in terms of system and subsystem design as well as mission analysis on study level and subsystem experience on implementation level within the ExoMars mission.

Based on this experience OHB System is well prepared to contribute to upcoming Mars studies and missions.

2. MARS SAMPLE RETURN OVERVIEW

The return of a Martian sample to Earth for thorough analysis in Earth laboratories is a long-term objective followed in a collaborative effort of ESA and NASA. The goal is to collect few tens of samples of various types accounting for a few hundred grams of total weight in the mid 2020s.

Although Mars Sample Return is generally considered feasible by the agencies, it is a complex multi segment mission, including at least the following missions:

- Landing mission(s) to deliver the **Mars Ascent Vehicle (MAV)** and a **Sample Fetching Rover** (SFR) to the Martian surface. The SFR has the task to bring pre-stored samples back to the Mars Ascent Vehicle, which is capable of launching the returned samples into a Mars orbit of about 500 km altitude
- **MSR-Orbiter** mission providing communication and retrieving the sample in Mars orbit, return it to Earth and ensure a safe re-entry through Earth atmosphere

The interfaces between the different elements are complex to handle and to optimise. Thus current activities are aiming at the consolidation of the mission architecture and its mission elements requirements. ESA is following this activity within the Mars Robotic Exploration Preparatory (MREP) programme.

The effective implementation will be depending on the progress achieved in several technology development activities in the coming years within ESA and NASA, e.g. the Mars Ascent Vehicle.

Based on the level of current uncertainties it may be necessary to prepare possible intermediate missions to MSR to cope with not reaching TRL in 2015 of all critical mission elements. According to ESA these intermediate missions shall ideally prepare for MSR, or provide generic technologies that are expected to reach the required maturity in time for the mission. Five mission candidates have been retained so far by the agency for down-selection at the next ESA council on ministerial level (end 2012).

- Network science mission
- Sample return from a moon of Mars
- Mars atmospheric sample return
- Precision lander (<10 km landing accuracy) with sampling and fetching rover
- Mars Sample Return Orbiter mission segment

Industrial assessment studies have been started beginning of 2011 for two missions, the MSR-O (Mars Sample Return Orbiter) and MPL (Mars Precision Lander). Both studies are currently under investigation in two parallel consortia each and have passed their Mission Definition Reviews this summer. OHB System is participating on both studies in the Thales Alenia Space consortium. In the following these missions will be further discussed.

3. MARS SAMPLE RETURN ORBITER

The goal of the MSR-O mission has to be seen in the context of the overall MSR scenario. MSR-O has to find and retrieve the orbiting sample, which was brought to a Mars orbit of around 500 km by the Mars Ascent Vehicle. After capture the sample will be bio-sealed and transferred into the Earth Return Capsule. The orbiter performs an escape manoeuvre from Martian orbit and transfers the sample to Earth. Upon arrival the Earth Return Capsule (ERC) will be separated and targeted for a safe atmospheric Earth re-entry. The orbiter will finally perform an Earth avoidance manoeuvre.

The mission is currently under study within the ESA MREP programme (Mars Robotic Exploration Preparatory Programme), co-financed by GSP and two parallel study contracts have been awarded. OHB System is part of the TAS-F consortium and taking care of MTP (mechanical, thermal and propulsion) for orbiter and propulsion stage.

3.1. Mission Architecture

Different mission architectures have been analysed through-out the first phase of the study. These architectures involve different launch scenarios like direct launch into a Mars Transfer Orbit (MTO), launch into a HEO (High Elliptical Orbit) with injection into the transfer orbit by on-board propulsive means and also the use of Earth Swing-by (ESB) trajectories.

For each combination a spacecraft composite consisting of an orbiter and a propulsive stage (if required) has been analysed based on ExoMars 2016 heritage. A possible design for the Orbiter Module is shown in the following figure.

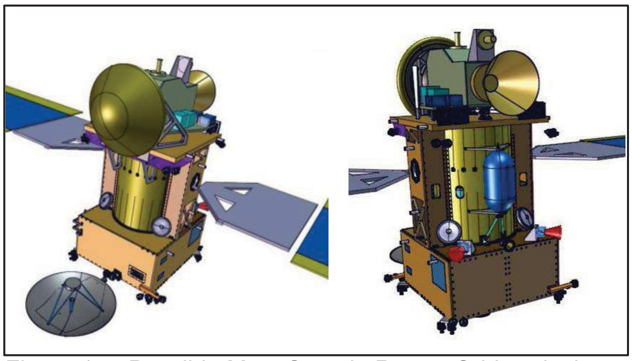

Figure 1. Possible Mars Sample Return Orbiter design

The baseline mission architecture considers dual stage spacecraft composites for direct injection to MTO or HEO injection including specific propulsion stages for each type of launch. The use of an ESB trajectory in combination with a dual stage spacecraft has been analysed but is not under further investigation in the second phase of the study due to schedule compatibility issue, but may be re-considered in future phases. The resulting spacecraft design for the ESB propulsion stage can be considered as intermediate case between the two other propulsion stages and significantly higher mass margin was found thus this mission will be feasible, if the others are feasible.

The baseline launcher is an Ariane 5. Launch windows are foreseen in 2022, 2024 and 2026.

The propulsion stages are sized to perform all manoeuvres from Earth departure until Mars Orbit Insertion manoeuvre. They will be separated in a stable Mars orbit before performing aerobraking with the orbiter spacecraft.

In Martian orbit the MSR-O will provide communication relay functionality for the MAV-lander, for the Mars Precision Lander (if required) and the surface assets and thus has to arrive well in advance.

The rendezvous with the sample will occur in a circular Martian orbit of about 500 km. After sample acquisition, the sample will be sealed and stowed in the ERC. For energetic reasons the full Orbit Sample Handling System (OSHS) will be jettisoned before Mars departure.

After reaching Earth the capsule will be separated and re-enters through Earth atmosphere for later retrieval and analysis in a curation facility.

3.2. Major challenges

The following main drivers have been identified:

- Launcher selection and associated performances
- Compatibility required with the other modules of the MSR mission (Lander, MAV, Surface assets)
- Maximization of probability of success
- Planetary Protection especially minimization of backward contamination risks
- Overall planning robustness (including manufacturing and AIT/AIV)

As baseline launcher the Ariane 5 has been selected. The current version of the launcher limits the possible wet mass of the MSR-O mission depending on the injection orbit. Several options have been studied including different launch options, transfer scenarios and even jettisoning of elements (e.g. Orbit Sample Handling System OSHS) after their use. Summarising all options the mission was found mass-wise feasible for HEO launch or Earth swing-by transfer scenarios for dual stage spacecraft composites. For a direct injection, mass is critical but this may be solved in the future by optimised trajectory analyses and the on-going Ariane 5 ECA performance improvement plan.

MSR-O is part of a mission campaign as described above and has interfaces to all other MSR elements of the overall MSR mission. It has to provide communication relay functionality for the descent of the MSR landing element(s) and ground assets like the Sample Fetching Rover. It also has to capture the sample delivered to a Martian orbit by the Mars Ascent Vehicle, which means that all parameters of the sample orbit have to be agreed between these two mission elements, e.g. orbit altitude, phasing and inclination. The orbiting sample (OS) does not have any manoeuvring capability after separation from the MAV.

The overall reliability of this mission has to be increased as far as possible but carefully monitoring all implemented redundancies to avoid unnecessary increase in complexity or reduction of overall MSR reliability.

Mars orbiter missions fall into the COSPAR Planetary Protection Category 3. The implications by planetary protection can with this category be handled by assembly in clean rooms, bio-burden control and appropriate cleaning measures. This was already done before for other Mars missions. In contrast, elements returning to Earth have to follow category 5 planetary protection requirements, which means that the probability of contaminating Earth has to be below 10^{-6}. Consequently high effort has to be performed to provide a reliable sealing of the returned sample and to increase the overall reliability of the spacecraft and mission e.g. by high fidelity components, dual or even triple redundancy on equipment level or by diversity. This has to be respected for the MSR-O mission. Consequently the sample has to be bio-sealed with three barriers. Sensors will check the containment of the seals to detect any failure immediately, which then prohibits any entering of the Earth return capsule into Earth atmosphere. All elements of the MSR-O having contact to the sample before sealing are considered contaminated and shall not return to Earth unsealed.

The return itself as well as the landing will also put high requirements on the design of the capsule.

Due to the close relation of the different mission elements the schedules dependencies have to be considered. The use of new technologies shall be limited to those enabling the mission and have to be at TRL 5 before a final decision on implementation can be taken. The development has to be followed closely to early identify any issues on ESA as well as on NASA side.

4. MARS PRECISION LANDER

The objective of this mission is to deliver a sampling and/or fetching rover to the surface of the Mars in the 2022-2026 timeframe with a landing precision better than 10 km to ensure that the rover is deployed in a reasonable distance to the previously prepared sample cache and the Mars Ascent Vehicle.

4.1. Mission Architecture

The Mars Precision Lander spacecraft is a composite consisting of the Descent Module and the Carrier Module. The Descent module is composed of the Lander Platform, the Back-Shell, the Front Shield and the Rover.

The spacecraft composite shall be launched by Soyuz Fregat with Ariane 5 as back-up. Launch periods in 2022, 2024 and 2026 are considered.

The spacecraft composite will be injected by the launcher either in a direct escape orbit or into GTO. All consecutive manoeuvres until Lander separation at Mars will be executed by the carrier spacecraft, but under control by the lander on-board computer. The carrier will provide the power for the full spacecraft composite during transfer and includes the high gain communication equipment and antenna. Control is exercised via trajectory correction manoeuvres. Position / velocity knowledge is maintained on the ground via processing of radiometric tracking measurements, which are used to initialize the Lander GNC prior the separation.

Even though the GTO injection provides a much higher mass at separation in both cases the mission is mass critical. This is one of the main drivers to be considered.

The propellant demand to be accommodated in the Carrier is largely affected by the launcher injection strategy: only the propellant for small correction manoeuvres have to be considered for the for direct injection case while in the case of GTO injection more than 1 t of propellant has to be accommodated for the Earth departure manoeuvres. The resulting Carrier designs are very different. The two designs are shown in the following figures 2 and 3.

The lander will be separated on a hyperbolic approach trajectory by a linear ejection mechanism a few minutes before Entry Interface Point and about 120 km above Martian surface. After separation

- The Carrier may execute a manoeuvre if necessary to ensure that no collision occurs between the different parts of the spacecraft composite and the planetary protection requirements are respected;

- The Lander will rely on its own GNC suite for implementing a 3-axis attitude control and coping with entry attitude requirement. The accuracy of the separation will thus directly impact the dispersion at entry, of the lander.

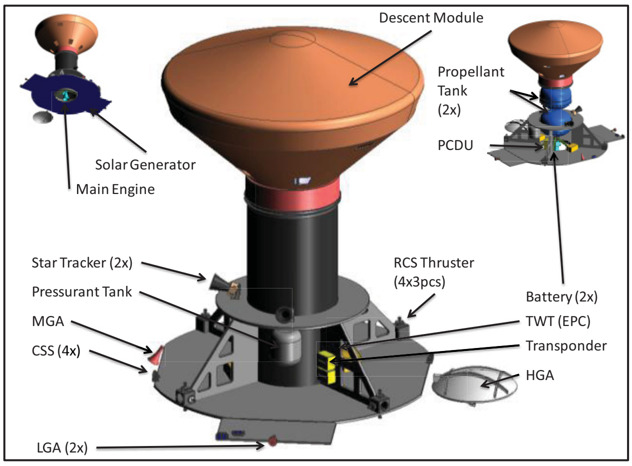

Figure 2. Mars Precision Lander Assembly for GTO injection

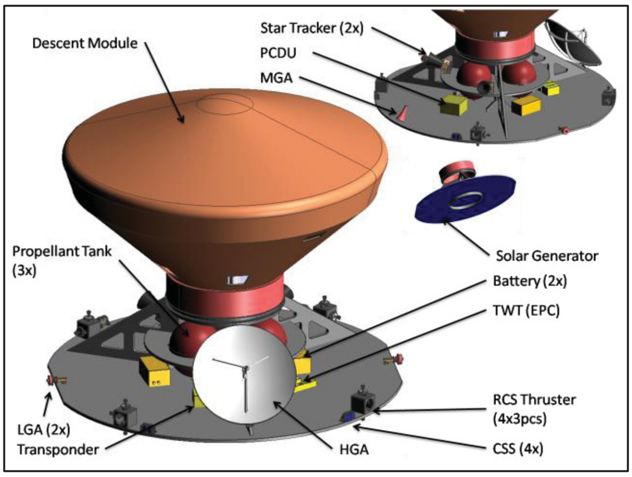

Figure 3. Mars Precision Lander Assembly for direct injection

To cope with the requirement of precision landing, a guided hypersonic entry phase starts at atmospheric entry interface and ends at deployment of the parachute. In this phase, lift is used to guide the lander to the target and to increase parachute deployment altitude (and thereby deliver more mass to the surface than otherwise possible). Control is exercised by rolling the entry vehicle about the relative velocity vector (bank control), varying the direction in which the lift vector is pointed according to commands computed by onboard entry guidance. Bank reversal is then needed to cope with the cross-range requirement.

The lander makes use of the ExoMars heritage as far as possible. At moderate mach numbers a parachute will be deployed to further decelerate the Lander. Before the start of the powered descent phase the front shield needs to be released and the parachute jettisoned. Thrusters will be used for further deceleration of the lander and a dedicated system starts the identification and avoidance of potential hazards on the surface. The system is designed for one divert manoeuvre. At about 10 m altitude the braking engines will be shut off. The terminal descent is a free fall of the lander. The impact shocks are damped by crushable structures.

The entire descent and landing system will touch down on the Martian surface, consequently the overall mission falls in the planetary protection category IV. Appropriate cleaning measures have to be implemented for the Lander and possibly for the carrier as well, depending on the implemented contamination barriers.

The MSR-O (or any other at the time available Mars Orbiter) will be used as relay satellite for the descent and landing system. During cruise the carrier is equipped with an articulated high gain antenna for X-band communication. For safe mode communication a MGA (Medium Gain Antenna) is included.

The carrier design, which is OHB System’s responsibility, is driven by the amount of propellant to be accommodated in the tanks and the need for sufficient power generation. For the GTO injection case a design was proposed at the mission definition review, which is based on a central tube as main load carrying structure. The design is presented in Figure 2. The large tanks are accommodated inside the central tube and mainly drive the overall system height.

The solar arrays are currently accommodated at the lower end of the central tube. This accommodation has the advantage of a simple interface and provides the opportunity to shadow the re-entry capsule. This ensures a stable thermal environment for it. Major disadvantages of the GTO design are the low Eigen-frequencies, which have to be counterworked by additional plies on the panel below.

Figure 3 presents the shearweb design for the direct injection case which only has to carry a small amount of propellant but uses the same approach for the solar array accommodation.

4.2. Major Challenges

The baseline launcher for the Mars Precision Lander mission is the Soyuz-Fregat, launched from Kourou. Regardless the final decision on injection orbit the mission has to be considered as mass critical, due to the mass limitation of the launcher.

The lander design is mainly driven by the aerodynamic entry at Mars but also considering the high mass growth potential of the overall mission resulting from additional mass accommodated in the Lander.

For the current carrier configuration the launch loads of Soyuz will be mass driving. On subsystem level standard design solutions have been selected to avoid development needs for the carrier.

5. SUMMARY

With the Mars Sample Return mission ESA and NASA have set an ambitious and scientifically highly interesting goal for the future of Mars exploration. Reaching this goal requires focused and continuous preparation within the agency and science teams but also within industry. Using the currently on-going mission studies the challenges of two mission candidates are more precisely evaluated leading to a better understanding of the whole mission.

OHB System AG is participating within these studies making use of its experiences with past and on-going Mars activities like ExoMars. By this, OHB System is deepening the understanding of Mars missions and preparing for participation in future Mars activities in the frame of Mars Sample Return, its precursor studies and missions as well as further Mars activities.