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Lunar Exploration Systems at OHB-System – An Overview

R. Janovsky, H. Müller, D. Lang, M. Scheper, D. Koebel, M. Katzkowski, K. Pauly, D. Hüser, J. Thaeter

OHB-System AG, Bremen, Germany

1. INTRODUCTION

Earth's moon has been re-discovered in the recent past as an attractive target for space exploration with robotic systems and eventually later-on its utilization, including a presence of humans on the natural Earth's satellite. Compared to interplanetary space exploration, technical, programmatic, cost and risk of moon exploration are by far lower. However it will still provide a huge amount of scientific return, on the Moon itself, the formation of this kind of objects and the solar system.

A number of system- and technology-studies relevant for the exploration of Earth's moon have been performed at OHB-System in the past three years, in various contracts for the German space agency and ESA. These work enclosed:

- The "Mona-Lisa"-study, aiming at defining a programmatic road-map for Moon and later Mars
- Lunar Exploration Orbiter "LEO", a feasibility study for a high-quality lunar observation mission
- "Next-Lunar Lander", and "Mona-Lisa-Lander" concept design studies for a medium-sized lander. It shall be capable to transport various payloads to the lunar surface, among them an astrobiological habitat and a scientific rover
- "Lunar crater exploration study" as part of the Mona-Lisa-study, to analyse from a system level point of view different methods to explore lunar craters. These methods are very demanding with regard to locomotion, communication and power supply.
- "LUNARES", in a team with Astrium and DFKI, to investigate different state-of-the-art robot technologies that can be specifically employed in these lunar crater terrains
- "Exploration Architecture Study", in a team led by CGS, to study and pre-design a lunar surface habitat as part of a lunar base
- "AMOR", a technology study with the objective to make use of lunar resources and to demonstrate the acquisition of lunar oxygen from regolith
- "Safir-Alfa", a feasibility study for a tele-communication relais-spacecraft in a Halo-orbit around the second Langrange-point of the Earth-Moon-system.
- ^{3}He from the moon, a study to explore chances and implications of this resource

This paper gives an overview on these studies related to the exploration of the Moon, shows the specific objectives and tasks as well as the design concepts derived in the various studies.

2. LUNAR EXPLORATION AT OHB

2.1. Mona Lisa

In the frame of the study called "Mona Lisa", which was partly funded by the German space agency DLR, a review of the interests of various groups within Germany was performed. Here, it was the goal to identify the "Best mission to the Moon from a German perspective". Some 70 expert scientists from a variety of scientific disciplines and research facilities within Germany were contacted. These were interviewed with respect to the mission objectives they desired to be linked to missions to the Moon. The scientific disciplines covered a broad spectrum, including:

- Planetology
- Cosmology
- Astronomy
- Astrophysics
- Chemistry (various)
- Geochronology
- Geodesy
- Zoology
- Microbiology
- Informatics
- Bio-technologies
- Ecology
- Toxicology
- Physiology
- Botanics
- Medicine

It became evident, that German scientists are interested in a huge number of objectives like planetology, gravimetry, cartography, astronomy, life science and lunar sample return. The main areas identified with regard to scientific aspects from the Moon may be summarised as follows:

- Global lunar mapping with spatial resolution < 5m, including geo-chemistry analyses from orbit
- Global lunar gravity field mapping, especially on the lunar far side
- Determination of local/residual magnetic field (from orbit)
- Seismic probes, laser retro-reflectors and heat flux probes to analyze inner construction of the Moon
- In-situ-analyses of lunar samples at geophysically interesting locations
- Lunar sample return from geophysically interesting locations
- Astronomy from the Moon, especially in the long-wave radio-frequencies and the infrared frequency domain,

- Observation of Earth
- Long-term effects of radiation/gravity on organisms, selection of adapted organisms
- Utilisation of Moon as test environment: verification of life support systems, organic fuel production technologies, automated diagnostic systems, etc.

One can state that although a number of missions were performed in the past, a variety of scientific questions linked to the Moon still remain unsolved. Prominent examples are the various hypotheses about creation and origin of the Moon, which still lack final confirmation. Furthermore, the technological progress made in the last decades today allows to investigate some phenomena with much better accuracy and more significant results, compared to earlier days. A systematic approach including the definition of ten mission alternatives able to serve the specified mission objectives and 27 weighted assessment criteria were defined. A brief overview on the mission alternatives and the required modules is shown in Figure 1.

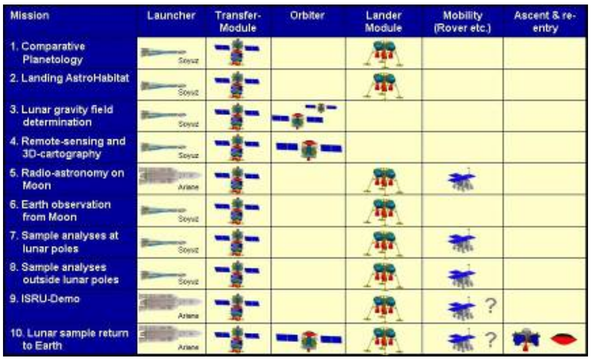

Figure 1: Overview on mission alternatives

A ranking of the missions in five criteria-groups and the overall ranking after the assessment is shown in Figure 2.

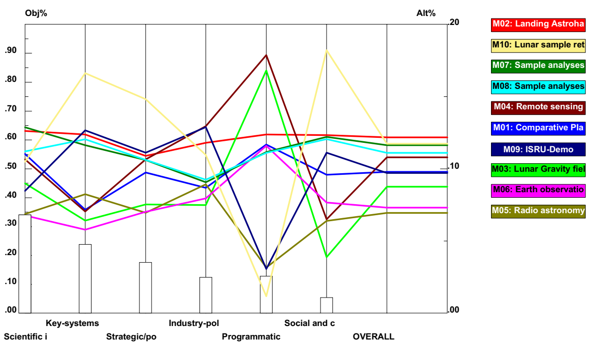

Figure 2: Overview on mission alternatives

Following the evaluation of the mission alternatives, the following most promising missions were identified:

- Landing of an astro-biological habitat
- Lunar sample return
- In-situ Sample analyses at various landing sites
- Remote sensing mission

In order to make use of a step-wise approach, mitigating technological risks, to provide time for the development of the enabling technologies and to adapt the mission sequence to the budget profile, the sequence of missions was defined as follows:

1. Lunar orbiter remote sensing mission
2. Lunar lander with robotic payload (astro-biological habitat, rover)
3. Lunar sample return mission
4. Human mission (participation)

The roadmap including these missions and their sequence is shown in Figure 3.

Figure 3: Mona-Lisa roadmap

The implementation of this road-map has been started, on a national level as well as on ESA-level by performing a number of feasibility and concept-design studies, as described following.

2.2. Lunar Exploration Orbiter

Under the contract of DLR, OHB-System and Astrium Friedrichshafen are the industrial Primes for the planned German Moon mission "Lunar Exploration Orbiter (LEO)". The German initiative for the LEO originated from the national conference "Exploration of our Solar System" held in Dresden in November 2006, where the science, industry and the agency jointly identified the need and opportunity to enter the international revived moon exploration activities.

Figure 4: OHB-System Phase 0 Concept Study for LEO

OHB-System was main contractor for one of two LEO definition studies in 2007. Together with its partners Kayser-Threde, von Hoerner & Sulger, TU

Munich, DLR GSOC, MT Aerospace and TESAT Spacecom, the feasibility of the ambitious goals has been evaluated. Results have shown, that Germany is well prepared to realize such mission in the time frame until 2012 with a predominant part of technology “Made in Germany”. Figure 4 shows a sketch of the proposed Phase 0 mission scenario and Orbiter.

With a total Launch mass of up to 2000kg, LEO can be launched with the Soyuz 2-1b carrier from the European launch site in Kourou. The lunar transfer is realized via a direct insertion into a Lunar Transfer Orbit (LTO). The main satellite will use the on-board propulsion system (bipropellant) for insertion into lunar orbit.

Figure 5 shows the LEO mission sequence. After main satellite commissioning, the space segment will first enter into first nominal orbit of 50 km average altitude and 85° inclination. After the deployment of the Sub-satellites and operations of 3 years, the main satellite will carry out an inclination change to the polar nominal orbit 2 in which it will operate for one additional year. After completion of the nominal mission, the LEO main Satellite may continue operations as part of an extended mission phase. After the LEO main satellite uses all of the onboard fuel, its orbit will degrade and eventually impacts the surface of the Moon.

The actual LEO concepts implements 14 experiments distributed over a main satellite and 2 subsatellites. The most noticeable goal of LEO will be the global mapping of the lunar surface with unrivalled high spatial as well as spectral resolution. In addition to the stereoscopic mapping a hyper-spectral screening with very broad bandwidth will be performed and also high accuracy gravimetric and magnetometric measurements and the determination of orbital dust. To reach the aspired high spatial resolution, a 50 km polar orbit is strongly demanded, with all the successive mission requirements. A four years mission operation will be needed to guarantee the global surface coverage.

The actual Phase A of the project aims to consolidate the mission requirements and concept studies performed in Phase 0 regarding the scientific goals as well as the LEO system elements. Together with Astrium GmbH Friedrichshafen OHB-System is industrial Co-Prime for the LEO mission and responsible for the LEO platform.

The actual LEO concept is based on the SGEO platform, developed in the frame of the ESA Artes-11 initiative which is aimed at the development of a general purpose small (Geostationary) satellite platform. The development of SGEO was initiated by DLR and OHB-System and is continued until today with a major German participation and OHB-System in the overall prime roll.

Analysis shows that the adaptation effort of SGEO to LEO is such minor, that SGEO provides the most reliable, but cost efficient solution for the German Moon mission and can provide sufficient resources to fulfil the LEO mission requirements. Major drivers for the main orbiter are identified with:

- Electromagnetic compatibility due to several frequency sources and receivers on experiment as well as communication side.
- High pointing stability and knowledge requirements
- High Data storage and transmission to Earth of up to 3000 Gbit/day
- Thermal Control complicated by significant Moon albedo

With LEO, Germany enters the first step in the MonaLisa Roadmap for Moon Exploration to ensure the a German lead position for the upcoming steps.

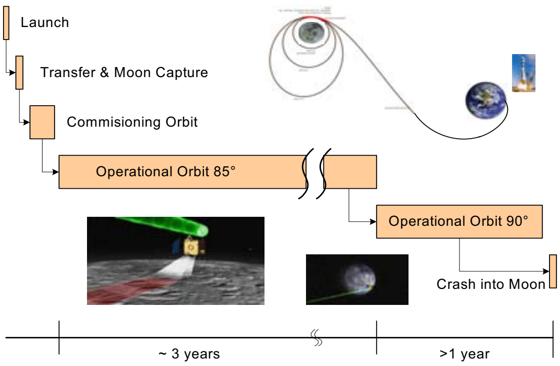

Figure 5: LEO Mission Sequence

2.3. Next Lunar Lander

The Aurora Programme has been set up by ESA in 2001 with the primary objective to create, and then implement, a European long-term plan for the robotic and human exploration of the solar system. Within this plan the exploration of Mars is identified as one of the main long-term objectives, and therefore two missions are foreseen as major milestones:

- In 2013 ExoMars shall explore the biological environment of Mars, and
- in the 2020 timeframe the Mars Sample Return Mission intends to collect several samples from the Martian surface and return them back to Earth.

Especially the second Mission calls for new technologies and capabilities in Europe. For this reason an intermediate mission, so called NEXT (Next Exploration Science and Technology) was originally envisaged by ESA which shall enhance and complement the capabilities acquired through ExoMars such as

- Rover systems
- Landing systems
- Power supply
- Autonomy and navigation

Presently, after studying a broad range of mission options, two different mission concepts are being studied at Phase A level:

- A Mars mission, demonstrating rendezvous and capture in Mars orbit and delivering a network of several surface stations
- A Lunar Lander mission, demonstrating high precision and soft landing with Hazard

Avoidance, focussing on in-situ science and mobility provided with a Rover as a baseline.

Currently three Phase A Lunar Lander Mission studies are executed by ESA starting in January 2008 with a duration of approximately 12 Months. Meanwhile the mission architecture elements are decoupled from the Mars Mission dedicated technologies. One of the three lunar mission studies is led by OHB, implementing and improving the experience gained in the previous Mona Lisa studies. The envisaged mission scenario is targeted to the transportation of a payload package of approximately 100 kg incl. a rover system near to the lunar south pole (southern than 85° S latitude and on near side longitudes) and for a minimum one year long operation of the payload. As launch system Soyuz ST-2.1.b-Fregat from Kourou is to be used. The baseline mission scenario is considering a GTO trajectory without using a dedicated transfer stage.
Since the environmental conditions and the mission requirements are specifically calling for a high precision soft landing and for hazard avoidance an emphasis of the study is given to the aspects of descent and landing including hazard avoidance. The derived concept for descent and landing is based on the utilization of an IMU in combination with optical sensors covering 12 critical phases and conditions:

- Lunar Orbiting
- Last Orbit Measurement
- Deorbiting
- Main Braking
- High Gate
- Guidance Correction Manoeuvres
- 1st Retargeting Manoeuvre
- Low Gate
- 2nd Retargeting Manoeuvre
- Terminal Gate
- Terminal Descent
- Touch Down

The navigation error which is regarded as the main contributor for landing dispersion shall be corrected by update of the IMU in the lunar orbit and during de-orbit by landscape navigation.
During trajectory correction manoeuvres the target scenery must stay in the FOV of Camera and LIDAR. The large scale hazard detection and piloting requires on the detection of e.g. large shadowed areas and steep slopes and rocks.

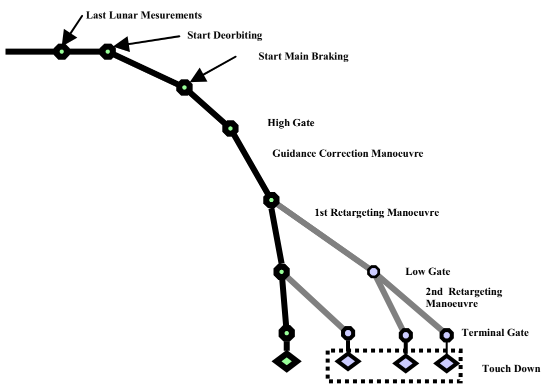

Figure 6: Descent and landing phases and Conditions

As shown in Figure 6, two phases are foreseen for retargeting manoeuvres at different altitudes for the case of hazards detection during the approach in order to optimize the autonomous selection of a safe landing site, within the lunar landing area which will be pre selected prior to the launch.
The lunar module consists of two elements, the lunar lander and the rover. While the rover is dedicated to the surface transport and to the execution of scientific experiments on the lunar surface, the lander has to serve for the functions of:

- Transfer Vehicle
- Landing Vehicle
- Payload accommodation and operations
- Rover accommodation and egress
- Communication between Moon and Earth

Figure 7 gives an overview of the NEXT Lander with deployed landing legs and rover egress ramps.

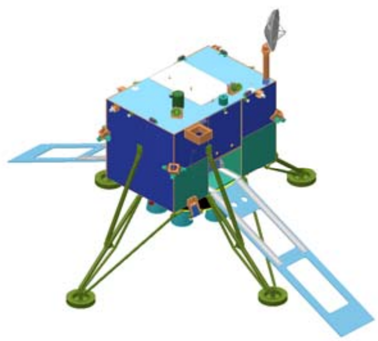

Figure 7: NEXT Lunar Lander

This scenario implies strong requirements on the power supply as well as on the autonomy of all systems on the rover and on the lander.
In order to provide mobility to dedicated experiments the rover shall drive to different measurement stations, which are to be defined during the operational phase. Waypoints are defining the path between the measurement stations. The navigation between waypoints is to be executed autonomously by the rover.
Concerning communication the three mission elements lander, rover and the terrestrial ground stations need to be linked in order to fit with the needed data rates and with the needed link availability for experiments and system operation. The resulting concept of the communication system

provides for a primary link between terrestrial ground station and the lander which shall function as relays also for the communication of the rover data. Therefore additional links are foreseen to allow the communication between the rover and the lander. As back up, a direct link is also foreseen between the rover and the terrestrial ground station to allow emergency commands from the ground. Figure 8 gives an overview on the concept for the surface operations.

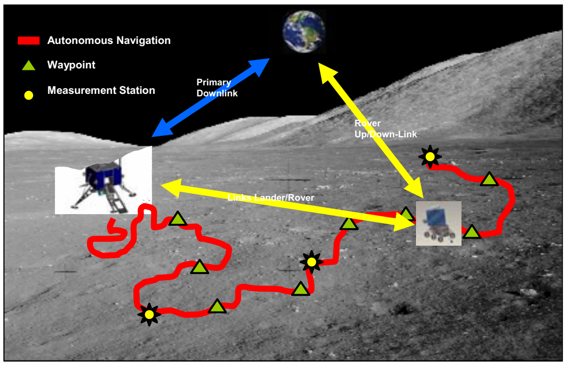

Figure 8: Surface Operations

The execution of the NEXT lunar lander mission is scheduled for 2016. In January 2009 the ongoing Phase A studies are to be finalized.

2.4. LUNARES

The aim of LUNARES is to evaluate different state-of-the-art robot technologies that can be specifically employed for the exploration of lunar craters. This exploration scenario will serve as a „Proof of Concept" for future cooperative and heterogeneous lunar missions using reconfigurable robots. In this project, a robotic team consisting of a manipulator arm, which is mounted on a lander, (see figure 9), a rover and a legged robot are tested in a realistic environment LUNARES will demonstrate how the already-existing robotic capabilities of the cooperating robotic elements are able to support scientific exploration on a planetary surface, and how these can be combined in order to create a complete robotic system, usable for different tasks, ranging from autonomous in-situ examinations to remote-controlled actions from an existing control center.

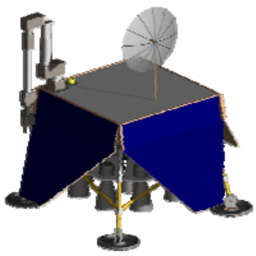

Figure 9: OHB's LUNARES Lander

To test these and future robotic systems, a realistic test environment reproducing a lunar crater and the illumination conditions as found at the poles of the Moon is set up, where the versatility and robustness of this reconfigurable robot system is investigated and demonstrated (see Figure 10).

Figure 10: LUNARES test bed with lander

The LUNARES project is partially funded by BIG/Bremen and the DLR. The project partners are OHB-System, Astrium and DFKI.

2.5. Exploration of lunar Craters

At OHB-System and in the frame of the Mona Lisa study, several strategies and technologies for the exploration of a typical lunar polar crater have been conceptually elaborated and designed. The overall scenario is based on the precision landing of a spacecraft on top of a peak of eternal light and in the vicinity of a polar crater. These craters are of great scientific interest, since it is believed that frozen volatiles and interstellar particles are embedded in the regolith within their eternal darkness. As a challenging measurement task, the analysis of 50 soil probes within the dark crater ground was required to be performed by all systems.

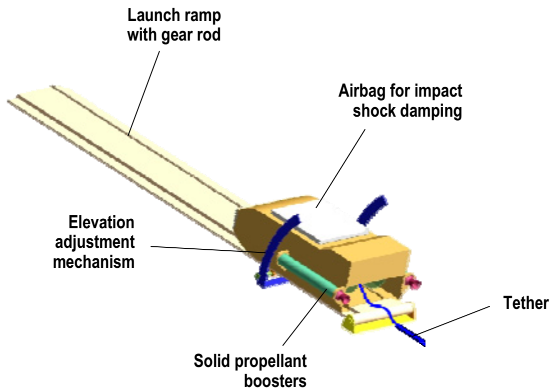

Figure 11: Rocket-propelled harpoon vehicle cocoon on launch ramp

Three entirely new exploration concepts have been investigated, the first of which incorporates a rocket-propelled harpoon system (Figure 11).

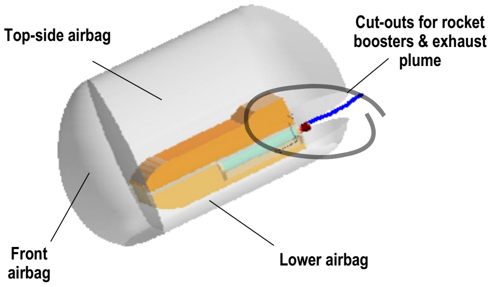

Figure 12: Flight configuration of harpoon system with inflated airbags

The harpoon is tether-bound and performs a flight trajectory that dives towards the centre of the crater. The touchdown is dampened by an airbags system (Figure 12). The tether provides the power supply by the lander spacecraft and the data connection.

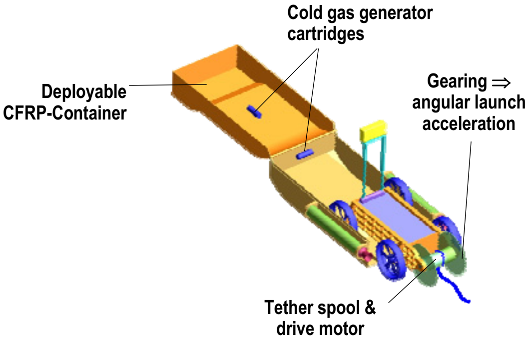

Figure 13: Tethered vehicle exiting CFRP harpoon cocoon

After the touchdown, the harpoon system releases a small wheeled vehicle (Figure 13). By re-winding the unrolled tether it drives itself backwards to the lander spacecraft and performs in-situ analyses of samples from the ground. Other crater exploration concepts not described here in detail included a measurement projectile ordnance system, which deploys the measurement sensors inside projectiles into the crater, as well as a autonomously flying "hopper" vehicle capable to land inside the crater at various positions and to perform their scientific measurements. Further, in a co-operation with the DFKI-Bremen, more conventional rovers using wheels, legs and tracks have been comparatively assessed.

2.6. Lunar Habitats

In the context of ESA's "Exploration Architecture Studies", OHB-System has been responsible for the pre-design of surface habitats for human missions to Moon and Mars. These studies aimed at long-term missions in the long-term future (human missions to the moon starting in 2025). For these scenarios, a generic habitat design including thermal analysis, CAD layout, as well as detailed mass and power budgets were derived (Figure 14). In the context of this work, it could be shown that a simple and cost-effective habitat design is feasible, without the need for new, expensive high-end technology development.

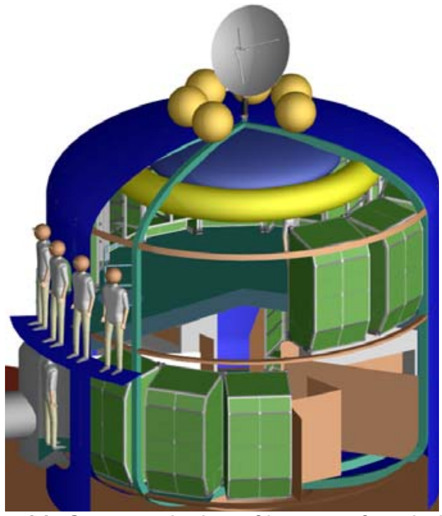

Figure 14: Concept-design of lunar surface habitat

The launch of the lunar surface habitat is planned to take place on Ariane-5 to low Earth orbit, followed by the transport to the moon by means of a transfer vehicle and to the surface using a cargo lander that provides for a soft landing, using a robotically prepared landing site (beacon), which reduces the requirements for the lander itself.
A "storm shelter" against solar proton events (capitalising on indigenous regolith material in order to reduce the total mass to be launched from Earth) was also included in the habitat design. This is a necessary feature in order to enable the required long-term stays of humans (up to 90 days on the lunar surface, over 400 days on the Martian surface).
The only habitat technology involved in these missions that features a technology readiness level lower than 7 are the "suitlock" surface EVA suits. This special suit type nonetheless promises significant advantages in terms of contamination issues by means of an ingress/egress route through a hatch in the back of the suit directly from and back into the habitat. Using this approach, the dust-contaminated / "dirty" exterior of the suit does not come into contact with the habitat's interior. This is an important aspect in particular in light of follow-on missions to Mars, where forward / backward contamination issues will prove to be paramount. Of major importance in this field will also be the question of long-term use of surface EVA suits. Future research in the realm of human spaceflight will have to concentrate on this aspect. In order to always have fall-back solutions available in case of potential surface EVA contingencies, a classical airlock is also part of the design.

2.7. Acquisition of Oxygen from Regolith

In 2006/2007 OHB-System performed a joint study on the subject of the Acquisition of Moon Oxygen Resources ("AMOR") together with the German Research Center for Artificial Intelligence (DFKI Robotics Lab), the Center of Applied Space Technology and Microgravity (ZARM) and the Fraunhofer Institute for Manufacturing Technology and Applied Materials Research (IFAM).
Lunar regolith consists of about 45 weight-% of oxygen. This resource will be mandatory for future

space exploration missions going beyond expedition-type missions, where the landing vehicles carry all consumables for lunar stay and return. Within AMOR, a community of specialists planned to build and operate a regolith processing demonstration plant in the south of Spain, where sufficient solar energy for the oxygen extraction process is available. The process is based on the reduction of Ilmenite ($FeTiO_3$) at a temperature of about 1000°C using solar heat. For the feedstock a volcanic lunar soil simulant is used, which will be collected with a robotic unit, facing the following challenges:

a) Lunar regolith consists of interlocking dust-like particles in a highly compacted soil, which requires high penetrating forces and special bearing techniques.
b) The collection-unit has to be light-weight, energy-efficient and autonomously controllable.

In this study the conceptual design for the three modules of the plant was performed:

- the regolith robotic collection unit,
- the process chamber and
- the oxygen post processing and storage unit.

Within the present AMOR activity an Earth Demonstration Facility (EDF) has been designed on concept level as depicted in Figure 15 to be built up in a later project.

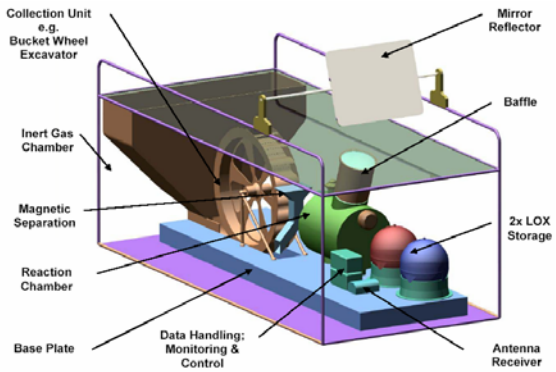

Figure 15: AMOR EDF concept (artists view)

The main key modules of the AMOR-EDF are:

- Lunar regolith collection system, based on space robotics
- Oxygen extraction chamber, based on hydrogen reduction with Ilmenite
- Oxygen post processing system, based on electrolyses, liquefaction and storage.

The work described here was partly funded by European Regions in the frame of the EraStar program.

2.8. Safir-Alfa

Subject of a short in-house study was to investigate the feasibility of a tele-communication relay satellite in a Halo-orbit around the second Langrange-point of the Earth-Moon-system (Figure 16).

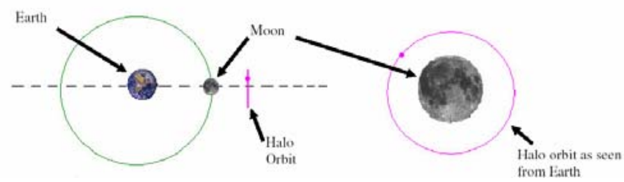

Figure 16: Halo Orbit in L2

The objectives, by positioning a spacecraft in this L2-Halo-orbit, is to have visibility to the Moon's far-side and to the Earth at the same time. This would highly improve the access to Moon's far-side, which is never directly visible from Earth. A permanent communication link will improve the operations of human or robotic elements at the lunar far side surface significantly (Figure 17). Subject of the study was to investigate the feasibility of the mission and system. Various transfer options as well as concept-design trades for the communication spacecraft were studied. A very mass-efficient method is to make use of a transfer along the stable and unstable manifolds EL2 and the stable manifold LL2, reducing the required ΔV significantly, but increasing travel-time to about 100 days (Figure 18).

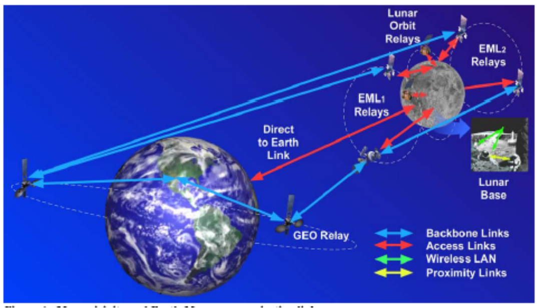

Figure 17: System with communications-Relais spacecraft in Halo Orbit L2 (**RD 1**)

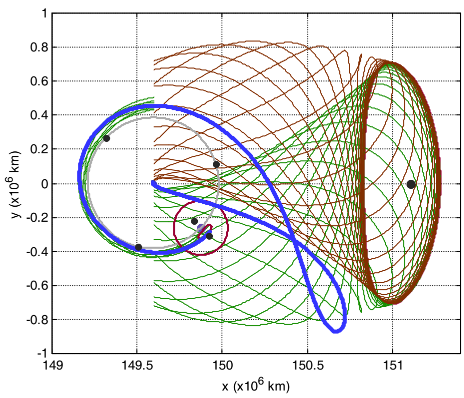

Figure 18: Transfer to Lagrangian point along stable and unstable manifolds (**RD 2**)

One key result of the study was, that the predicted effort to keep the spacecraft in its Halo-orbit differs significantly. Depending on the model taken from literature, the ΔV for orbit-maintenance varies significantly. Thus, the conclusion of the study was in a first step to do more research on the Halo-orbits and their maintenance needs, to perform a pathfinder-and technology demonstration mission to an Halo-orbit and in the next step, based on a mature model for the orbit perturbations in the L2-Halo-orbit, to continue with the design of an operational relais spacecraft.

2.9. Future Studies: ^{3}He from the Moon

Objective of an ongoing activity is the study of the utilisation potential of lunar ^{3}He on Earth. ^{3}He has been deposited on the lunar surface as particle flow coming from the Sun during billions of years. Due to the absence of a lunar atmosphere and other erosion processes it is expected, that the density of this resource is higher by orders of magnitude on the moon than on Earth. We are aware that gaining ^{3}He from the moon as future energy resource for life on earth is a very visionary view. The facts that:

i) all transportation to and from Space is today very costly and
ii) a fusion reactor for burning ^{3}He is in a very early development stage, only

makes the utilisation of lunar ^{3}He questionable.
However, the exploding prices for fossil energy resources during the past 30 years and their timely limited availability allows to study such an approach. From today's point of view about 100 tons of ^{3}He per year would be enough to provide the entire earth with electric energy. In comparison: 1 ton of ^{3}He provides the same energy as $20x10^{6}$ tons of crude oil.
The process of gaining Oxygen and 3He is quite similar, at least partly. The moon regolith has to be heated in a process chamber to about 900°C in order to remove the gas from the solid. This process is preferably done during the daylight periods on the moon. This gas mixture has to be separated at low temperatures (~ -200°C) by condensation until He – gas is left. The separation of ^{4}He and ^{3}He is done by isotopic separation below 3.2 K. The technologies for such a gas treatment exist on earth. These two processes have to be done during the night periods on the moon for reason of energy saving measures.
One should not forget the rare deposits of ^{3}He on the moon, i.e. one has to process 75.0000 tons of regolith for 1 ton of ^{3}He.
OHB-System is undertaking technical, programmatic and especially commercial investigations for the terrestrial utilisation of ^{3}He. We are discussing, developing and trading various infrastructure and logistic scenarios for building up a ^{3}He production plant on the moon and for transportation from moon to earth.
The implementation of such scenarios will be an immense expense, but probably justified by an enormous future value.

3. SUMMARY & CONCLUSIONS

The Moon came again into the focus of lunar exploration, after many years of non-observance. This is due to the fact, that, taking into account the progress made in the last decades, today a number of new technologies became available to perform science on and from the Moon with a new level of quality. Not only the means to do research on the Moon have been improved, but also a huge number of new and challenging scientific questions appears, where the answer can be found on the Moon. The answer on these questions does not only have relevance for the Moon itself, but also for Earth and the solar system.

Taking into account these developments, a number of of activities to foster lunar research have been started in the past. This includes not only the scientific world, but also industry, starting activities to investigate enabling systems and technologies.

OHB-System has contributed to this development in many fields, by performing studies on scientific objectives and payloads for lunar exploration and pre-design of enabling systems and technologies. This includes the development of first demonstration activities too. Thus, OHB-System is due to its proven know-how and experience in these fields well prepared to support many kinds of lunar exploration missions in the near-future in a leading role.

4. REFERENCES

RD 1: Bhasin, Hayden, 2004
RD 2: Parker, Lo