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ESA strategy for human exploration and the Lunar Lander Mission

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Abstract. As part of ESAs Aurora Exploration programme, the Agency has defined, since 2001, a road map for exploration in which, alongside robotic exploration missions, the International Space Station (ISS) and the Moon play an essential role on the way to other destinations in the Solar System, ultimately to a human mission to Mars in a more distant future. In the frame of the Human Spaceflight programme the first European Lunar Lander Mission, with a launch date on 2018, has been defined, targeting the lunar South Pole region to capitalize on unique illumination conditions and provide the opportunity to carry out scientific investigations in a region of the Moon not explored so far. The Phase B1 industrial study, recently initiated, will consolidate the mission design and prepare the ground for the approval of the full mission development phase at the 2012 ESA Council at Ministerial. This paper describes the mission options which have been investigated in the past Phase A studies and presents the main activities foreseen in the Phase B1 to consolidate the mission design, including a robust bread-boards and technology development programme. In addition, the approach to overcoming the missions major technical and environmental challenges and the activities to advance the definition of the payload elements will be described.

1. Introduction

As part of ESAs Aurora Exploration programme since 2001, the Agency has defined a road map for exploration whereby, alongside robotic exploration missions, the International Space Station (ISS) and the Moon play an essential role on the way to other more ambitious destinations, ultimately to a human mission to Mars in a more distant future.

Consistently, in the last years, ESA, with the support of its Member States, has investigated options for the development of enabling capabilities in exploration and considered several types of missions, which would foster this development. As a result of this investigation, and in line with the growing interest in Lunar Exploration of the world space powers, the Moon has emerged as a key stepping stone for the demonstration of technologies, with a Lunar Lander mission representing a key opportunity for Europe in the coming decade. The Lunar Lander will be the first European mission to land on the Moons surface. The current targeted landing sites are located in the South Pole region of the Moon, a region still unvisited and a promising destination for future human missions.

1.1. Mission objectives

The primary objective of the Lunar Lander mission is to demonstrate Europes ability to deliver payload safely and accurately to the Moons surface. Central to achieving this objec-

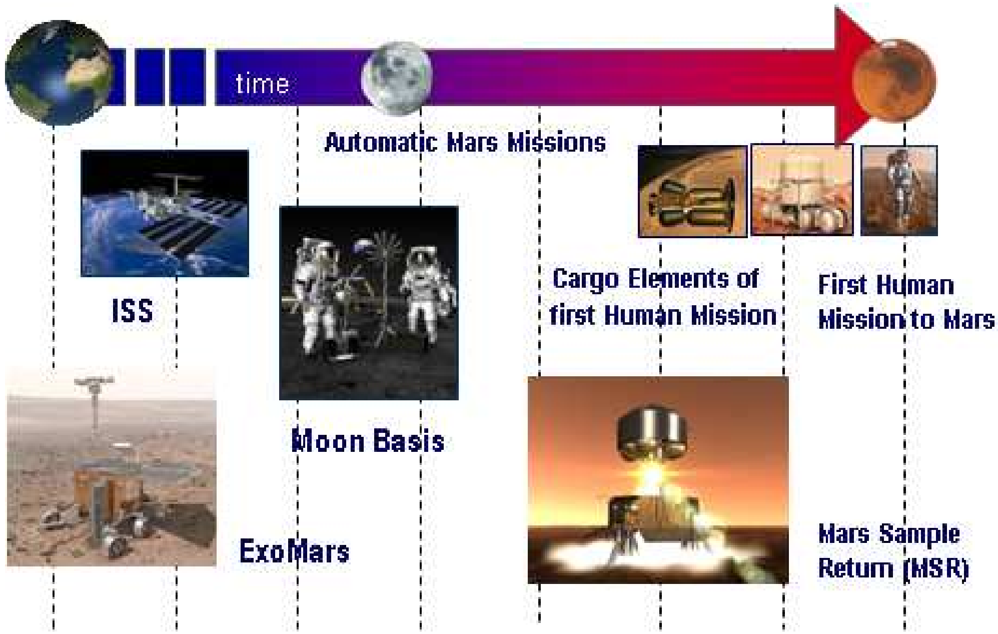

Fig. 1. Aurora Exploration Roadmap

tive is the Guidance, Navigation and Control (GNC) subsystem and its interfacing with other subsystems, primarily propulsion. The highly variable terrain of the South Pole region makes soft precision landing with hazard avoidance a must for the mission. Once on the surface the Lunar Lander mission will perform scientific experiments addressing key issues for the sustainability of future human exploration. These include advancing our understanding of the lunar radiation and dust environments, and their effects on human health and the systems needed to support exploration. Payloads on board the lander will also examine the lunar regolith closely to characterize the mineralogy at the landing site, and to investigate the availability of possible resources which may be used by future exploration missions.

1.2. Landing site selection

Selecting a landing site for the Lunar Lander mission is inextricably linked with the mission objectives and, perhaps more importantly, with the decision to avoid the use of Radio-Isotope devices, such as RHUs or RTGs, to support thermal control and power generation. Such decision was taken during the course of the Lunar Lander mission study in order to reduce the programmatic risks associated to the current unavailability of such devices within Europe. Many of the mission objectives highlight the desire to operate for longer than 14 days, which without the aid of radioisotope devices poses significant problems at most surface sites where illumination is only available for 14 days per month. The South Polar region presents locations for which the altitude of the terrain with respect to surroundings is such that, due to the fact that the Moon polar axis is almost perpendicular to the ecliptic, illumination is available for periods far in excess of 14 days, only interrupted by short periods of darkness, which can be withstood by conventional thermal and power subsystems design. Analyses carried out at ESA (Vanoutryve et al. 2010) and by European industry, based on the terrain data from Kaguya laser altimeter (LALT), have indicated that such sites do indeed exist and may offer sufficient illumination to support mission durations of up to several months, depending on the capability of the lander to survive short periods of darkness (tens of hours). Such sites have also been found to be limited in extent, which requires a very tight landing accuracy to the on-board GNC system. The direct communications to Earth have also been analyzed, and show a regular pattern of approximately 14 days of visibility and 14 days of occultation, although some sites further from the pole offer longer visibility. The results of the illumination and communications analyses will be verified using more accurate data from NASAs Lunar Reconnaissance Orbiter (LRO) as these become available, and will feed into the lander design, in terms of GNC, thermal and power sub-systems.

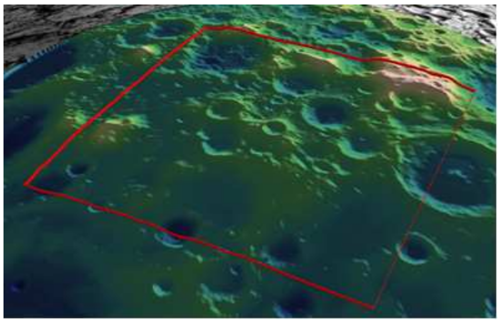

Fig. 2. Potential landing sites identified at the Lunar South Pole

2. Mission baseline

The mission baseline for the Phase B1 industrial study has been identified based on investigations into a Soyuz class mission scenario, carried out through three parallel industrial phase A studies. As a result of the Phase A studies it was found that GTO and HEO transfers both appear feasible allowing comparable payload masses to be delivered to the lunar surface. A dual stage architecture was found to give marginal payload mass gains over a single stage architecture, and was therefore discarded due to the associated increased complexity. A combination of 500 N European Apogee Motors and 220 N pulsable Automated Transfer Vehicle (ATV) attitude control thrusters resulted into the best combination of engines available in Europe. A payload mass of 60 kg has been allocated, to be confirmed in phase B1. This shall include all instruments and associated servicing equipment. During the anticipated 6-8 months mission life-time the operations of the payload will be driven strongly by the pattern of short periods of darkness which can be expected to occur intermittently and by the availability of the communication windows to the Earth. In fact, no orbiter is assumed in the mission architecture and the communications are via direct-link, which implies at the South Pole about 15 days per month without communications.

Fig. 3. Lunar Lander concept

3. PHASE B1 activities

The Lunar Lander Phase B1 activities, financed by Germany, Portugal and Canada, have recently been kicked off (August 2010) with EADS Astrium (D) as Prime Contractor. This activity includes a mission design part and an extensive programme of bread boarding activities. In parallel to the industrial phase B1, several activities are being carried out, including a consolidation of the launcher performance and trajectory analysis, landing site characterization, GNC technology development activities in the frame of the Aurora Core programme and payload definition studies financed by the ESA General Study Programme (GSP).

3.1. Mission design

A detailed analysis of the most recent lunar South Pole data will be conducted, and the key parameters of the promising landing sites will be characterized, including: illumination and darkness as well as communication profiles, physical size and associated hazard distribution (e.g. slopes, boulders, shadow). Based on the results of this analysis, the impacts of the landing site characteristics on power and thermal subsystems as well as the required descent & landing strategy to meet the landing accuracy and hazard avoidance requirements will be assessed. Once the landing site(s) agreed, a detailed iteration at system and subsystem level will be performed, including descent & landing, thermo-mechanical, electrical and software subsystems. Besides, critical mission and operations aspects will be assessed, including interaction with ground prior to and during the descent & landing sequence, as well as the operational strategy once landed to ensure payload operations and spacecraft survival during short-darkness periods. Several reviews will be implemented in the course of the mission study, including a Polar Landing Review (PLR, Spring 2011) in order to verify progressively the feasibility of landing in the South Pole region, taking into account the landing site characteristics, a related compatible spacecraft design, as well as the estimated overall payload capability. The Phase B1 contract shall culminate in a Preliminary System Requirements Review (Pre-SRR, spring 2012), which shall provide the basis for subsequent definition of the individual Lander sub-systems at a more detailed level.

3.2. Breadboarding activities

Parallel to the mission design activities, a set of breadboarding activities will be carried out to address those critical aspects of the mission which will require early development. Areas already identified include propulsion, GNC (both hardware and software), avionics, thermal control (in the extreme environment on the Moon without the use of RHUs). In the area of propulsion, several tests have been identified to characterize the behaviour and performance of the complex engine cluster: flow interaction tests with water, will allow the investigation of the interactions and disturbances in the feed system; hot firing tests of the 220 N engines will characterize the performances of these engines at 2.5 Hz (TBC) modulation frequency (1Hz qualified for ATV); pressure regulator tests will enable a measurement of the pressure regulation accuracy at high mass flows. In the field of GNC, a Relative Navigation and HDA demonstration test will be performed with hardware in the loop on the TRON dynamic test bench (DLR Bremen), using a representative Lunar surface model. Concerning Absolute Navigation, two activities have been planned: an Absolute Navigation rapid prototype, for specification and implementation of systematic performance analyses, and an Absolute Navigation demonstration test, to evaluate the Absolute Navigation performances using the TRON indoor test facility.

3.3. Technology development

One of the Lunar Lander missions primary objectives is to demonstrate the technologies and capabilities associated with safe and precise landing, see Philippe et al. 2010. As such, the technology development effort required as part of the overall mission design is extremely important. In addition to the descent and landing technologies, elements such as propulsion, thermal control and power storage all pose technical challenges for the mission. As part of ESAs Aurora Core Programme a batch of development activities have been initiated to mature key technologies and component elements for descent and landing GNC. Further activities will be pursued on terrain relative navigation sensors, navigation and hazard avoidance techniques and software and on the tools and facilities required for their validation. These will form part of a set of pre-development activities which shall be carried out as part of the Lunar Lander project activities up to the end of Phase B. All of these pre-development activities will aim to achieve a TRL of 5-6 by the time of the Lunar Lander missions Preliminary Design Review planned in 2014. Technology development and demonstration is also an important consideration for the payload elements of the Lunar Lander. While many of the instruments included in the model payload have a strong background, and in some cases flight heritage, several elements will require efforts to develop key technologies and to adapt existing ones to the lunar environment.

4. Payload objectives and definition

In order to identify the objectives for the payload and surface operations phase of the mission, the following questions were addressed: what needs to be done to prepare for future human exploration, in-situ on the Moon, and what can be achieved with a precursor mission? Having provided answers to these questions allowed the identification of potential objectives for the mission. The candidate objectives were then assigned as high, medium or low priority based on their criticality for future human exploration. A complete list of potential objectives for the payload and surface operations can be found in Fisackerly et al. 2010. A comprehensive discussion of the background to these objectives, their formulation and their justification is provided in Carpenter et al. 2010. The requirements for a mission and its payload to meet the objectives when performing these investigations were also derived. These requirements can be divided in to the following two categories:

- Mission requirements (e.g. payload mass, landing site, mission duration, mobility etc.)
- Payload requirements (e.g. elements/minerals to be observed, accuracy, sensitivity etc.)

Recommendations for potential instrument types/concepts which could meet the derived requirements and thus achieve the mission objective were made. These were derived for the most part from the responses received following the 2009 Request for Information, which saw a very large number of ideas submitted by scientists, research institutions and industry. Within this theme some key areas were identified in which significant work was required, and for which in-situ investigations on the lunar surface were mandatory: Crew health, Habitation, Resources and Preparations for future human activities. A combination of the results of the phase A studies, indicating feasible mission scenarios, and the candidate objectives for surface operation phase of the mission have been combined to determine a model payload and objectives for the mission which are likely to be achievable and have a high value for the future. This formulation provides the initial input to the phase B1 of the mission design.

4.1. Model payload

Of all the potential instruments an optimal set must ultimately be selected, whose mass (including the mass of any associated servicing equipment) is within the ~60 kg available. Instruments for the model payload were selected on the basis of: relevance for near to medium term human exploration preparations; technical maturity; implications for system complexity; likelihood of meeting payload requirements in the nominal 6 8 months of operations. A preliminary payload model is presented in the Table depicted in Fig. 4. The table also references the high and medium priority objectives which can be addressed by each instrument type. All instruments identified for the model payload have been identified as a potential means by which to meet requirements generated in the definition process and thus achieve identified mission objectives. A detailed description of the model payload elements can be found in Fisackerly et al. 2010. Also included in the model payload is a Mobile Payload Experiment (MPE), a contribution in-kind from DLR, which represents an opportunity for the robotics, autonomy and surface mobility communities to develop and demonstrate light-weight, low power con-

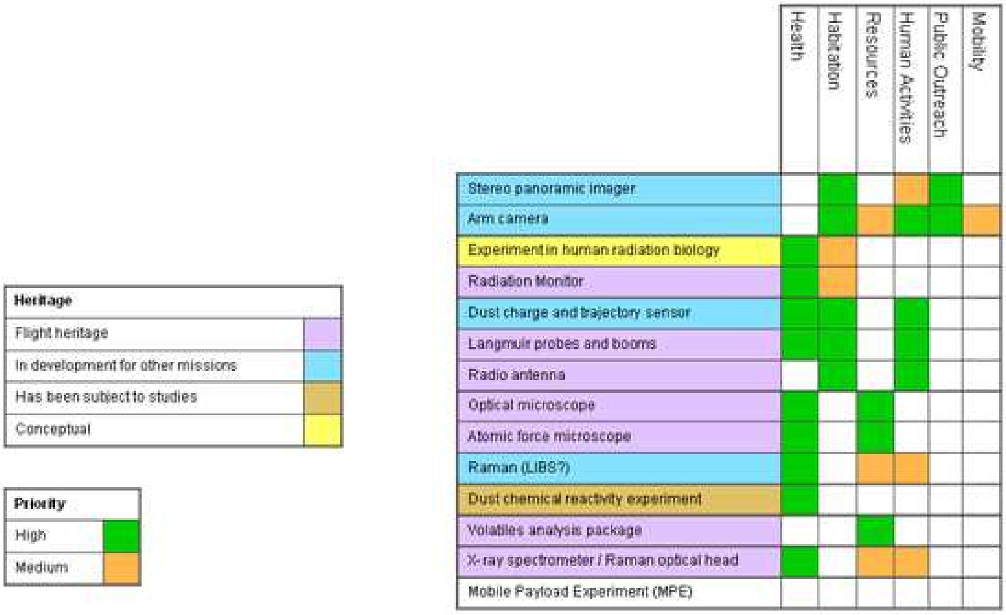

Fig. 4. Potential landing sites identified at the Lunar South Pole

cepts for future surface exploration missions. The model payloads function is to inform the mission studies and to identify areas where development of instrumentation and technologies is required. It does not represent a final selection of the payload instruments, which will occur at a later date following a formal call for proposals. Such a call should to occur in 2012. As the application of these instruments to meet the objectives described and the accommodation and implementation of the payload within the mission become better understood it is expected that the model payload may be further refined and optimized.

4.2. Payload definition studies

In order to support the definition of the payload a set of payload definition study activities is foreseen, to run in parallel with the Lander Phase B1 activities. These studies will investigate packages of instruments, which may be derived from the model payload, and which address the various mission objectives identified, focusing on areas where a potential synergy has been identified between instruments and benefits may be obtained through commonality of design. The objectives for these activities are:

- To assess the requirements for the experiments including an assessment of the constraints and challenges arising from operating in the lunar environment.
- To review and trade-off potential technologies and their application to achieving the requirements.
- To perform a preliminary definition of the instrument and package designs and operations, including the requirements placed on the lander platform.
- Establish a flight model development plan, in terms of both design and technology development, to mature the packages for flight on a Lunar Lander mission in 2018 and achieve TRL 5-6 by 2014.

A description of these activities is given below. A more detailed description can be found in

Fisackerly et al. 2010.

Autonomous Microscope for the Examination of Radiation Effects (AMERE)

This activity will investigate a potential experiment to quantify the physiological effects of deep space radiation on the Moon. The constraints of the mission present considerable challenges for the development of an experiment which addresses these issues in a meaningful way and yet remains within the available resources and scenario.

Lunar Dust Analysis Package (L-DAP)

The objective of this activity is to study a package for the in-situ microscopy and compositional analysis of lunar dust (including: Size distribution for particles from 10s nm -100s μm; Shape and structure of grains; Chemical and mineralogical composition of particles), defining requirements and feasibility, and performing a preliminary design to provide inputs to the Lunar Lander project.

Lunar Dust Environment and Plasma Package (L-DEPP)

The objective of the activity is to study a package to determine the charging, levitation and transport of lunar dust, in-situ on the Moon, and the associated properties of the local electric fields and plasma environment. The study will define requirements and feasibility, perform a preliminary design and provide inputs to the Lunar Lander project on a suite of instruments to determine the properties of levitated lunar dust, the plasma environment, the local electric fields, and resultant effects in the radio regime, including: The charges on levitating lunar dust particles; The velocities for levitating lunar dust particles; The trajectory of levitated dust particles; The temperature and density of the local plasma; Electric surface potential; Observe radio spectrum (with an additional goal to prepare for future radiation astronomy activities).

Lunar Volatile Resource Analysis Package (L-VRAP)

The objective of the activity is to define a package to measure the species of volatiles present at the lunar surface, their abundance and distribution from a landed platform and demonstrate their extraction, as a precursor to future in-situ resource utilization in human missions. The study will define requirements and feasibility, perform a preliminary design and provide inputs to the Lunar Lander project. The instrument package is required to extract the volatile molecules from lunar soil and analyze them to determine the species present and their relative abundance. The primary mechanism for performing such an analysis is expected to be mass spectroscopy, although additional complimentary measurements may be considered. The potential effects of contamination by the Lander may be critical and so quantifying the likely contamination and its effects will also be addressed.

5. Future steps

The aim to launch the European Lunar Lander mission by 2018 imposes a challenging schedule on the mission development. However the experience gained through the Phase A activities and the preparatory technology work has created a solid foundation from which to move the project forward. The next step is already under way with Phase B1 activities initiated, including both mission design activities as well as breadboarding of key technologies. During the Phase B1 work, key choices will be assessed including the implications of the selected landing site(s). As part of the expansion of the Lunar Lander project, additional industrial partners are in the process of being integrated into the consortium. At this stage these companies are from those countries expressing an immediate interest in joining participation to the project, however every effort shall be made to broaden the participation still further to all those countries with relevant expertise. Following from Phase B1, a Bridging Phase shall be implemented to carry the project beyond the next Ministerial Council in 2012. At the Ministerial Council meeting in 2012 the project will seek the support of ESA Member States for the implementation of the Phase B2/C/D of the mission.

6. Conclusion

The Lunar Lander mission is an important opportunity for Europe to demonstrate its capabilities and to conduct research in-situ to advance its development of longer term human exploration systems. With the activities already completed, as well as those put in place and planned up to 2018, the technical aspects of the mission shall be addressed. Future human space exploration beyond LEO will present new opportunities and new challenges, but with missions such as the European Lunar Lander, those challenges can be practically addressed step-by-step.

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