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# THE EUROPEAN LUNAR LANDER: A HUMAN EXPLORATION PRECURSOR MISSION


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The European Lunar Lander is a mission in development within the Human Spaceflight and Operations Directorate of the European Space Agency (ESA). Planned for launch in 2018 and a landing near the Moon’s south pole, the mission’s primary objectives include the demonstration of safe precision landing technology as part of preparations for future international cooperation on robotic and human exploration of the Moon. Once on the surface the lander shall carry out experiments and investigations to better understand the Lunar environment and specifically how it might affect future robotic and human exploration activities.

Technical and scientific factors have highlighted the south polar region of the Moon as an attractive destination, however targeting specific landing sites which possess the right characteristics imposes demanding requirements on landing precision and hazard avoidance capabilities. The surface environment at the poles also provides challenges in terms of the operation and survival of the platform. Addressing these challenges is not only key for the Lunar Lander mission, but also prepares Europe technically for future exploration missions.

In the following sections the Lunar Lander mission is described in terms of its timeline, architecture, payload and operations. Subsequently the key challenges are discussed as well as the project’s approach to dealing with these within the overall development framework.


## 1. MISSION OUTLINE AND OBJECTIVES

The Lunar Lander is currently engaged in Phase B1 under lead of the prime contractor Astrium GmbH (Bremen, Germany), which includes mission definition, system & sub-system design and technology breadboarding activities. This Phase shall be completed in autumn 2012. Important decisions taken as a result of extensive Phase A work, and which provide the foundation for the mission definition in Phase B1, include the use of a Soyuz 2-1B launch vehicle, the exclusion of radio-isotope devices (e.g. RHUs/RTGs) from the design, the targeting of a southern polar landing site and the exclusion of an orbiter as data relay.

### 1.1 Mission Architecture

Launching from Centre Spatial Guyanais in late 2018 on a Soyuz launcher, the lander spacecraft is injected into a high elliptical orbit by the Fregat upper stage. The spacecraft then uses its own propulsion system to transfer to the Moon lasting several weeks, via intermediate high elliptical orbits. It finally injects itself into a polar orbit around the Moon. The stay time in Lunar orbit before landing depends on several factors including the need for checkout and calibration of the systems critical for landing, as well as the possible need for waiting time to ensure the correct orbit orientation with respect to Earth, Sun and Moon, and to accommodate margins for contingencies; this stay in orbit is expected to last from a number of weeks up to a maximum of 3 months.

Once cleared to initiate the descent and landing sequence the lander starts out on its descent trajectory, beginning with a de-orbit burn, followed by a coast phase for around half an orbit until reaching an altitude of ~15km, at which point propulsive descent initiation (PDI) occurs which marks the start of the main braking phase. Firing all five of its 500N main engines and off-modulating an additional set of 220N pulsable thrusters the lander reduces its altitude to ~2-3 km and its velocity to approximately $60ms^{-1}$, while controlling its attitude.

Starting from the coast phase of the descent, the lander uses visual data acquired from the surface to autonomously perform precision navigation and to ensure a correct positioning of the lander throughout the critical phases of landing. During the final kilometres before touchdown the lander reduces the level of thrust to ensure a fuel efficient trajectory. It is during these final few minutes that the lander performs Hazard Detection and Avoidance (HDA) to identify hazardous slopes, obstacles and shadowed areas, carrying out avoidance manoeuvres if necessary, as in Figure 1. Finally the lander performs a controlled vertical descent and touchdown on the lunar surface, absorbing any remaining velocity in its four landing legs.

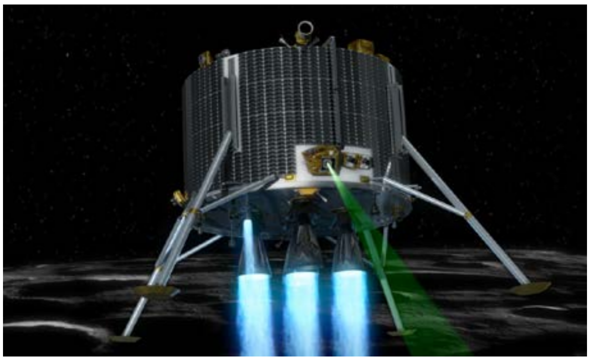

Fig. 1.The Lunar Lander during final phases of descent, scanning the surface for hazards.

Once on the surface the lander carries out critical operations such as relaying the complete package of data relating to the descent and landing sequence back to Earth. It also deploys its antenna and camera mast and acquires the horizon in order to derive the exact illumination pattern at the landing site and adapt the operational scenario accordingly. Nominal surface operations are then initiated which includes the deployment of specific payloads onto the lunar surface via robotic arm, the activation of other static monitoring payloads onboard the lander, and ultimately the acquisition of surface samples using the robotic arm for analysis by instruments on the lander.

Surface operations are critically dependent on the availability of solar illumination, which can vary depending on the local topography of the landing site and on the direct visibility of the Earth ground station for communications.

### 1.2 Payload Definition

The Lunar Lander model payload has been established according to objectives aligned with human exploration preparation[1]. This includes detailed investigation of surface parameters of strong significance for future operations on the surface, be they human and/or robotic.

To provide industry with a solid reference to progress in the spacecraft design during Phase B1, specific payload packages have been defined to address the:

- microscopic properties of dust, including shape & size distribution, and its composition
- plasma and electric field environment on the lunar surface, and the behaviour of dust within that environment
- feasibility of making radio astronomy measurements from the lunar surface
- potential volatile content of regolith (e.g. OH)
- radiation environment at the lunar surface
- camera package for visual data from the south pole environment

These payloads can be accommodated either statically on the lander body, held at distance from the lander by dedicated booms, or are deployed in close proximity to the lander (1-2m) by a robotic arm. Payloads which analyse samples of regolith close-up will receive small amounts of material gathered from the vicinity of the lander by an acquisition device on the end of the robotic arm.

In addition to these payloads, a specific package has been defined termed the Mobile Payload Experiment (MPE) which is a contribution-in-kind currently under study by the German Space Agency, DLR.

While all of the elements described above have been defined according to the mission's overall surface objectives and are used as model payload for the mission study, final payload selection shall take place following decision on the project's continuation at the next Ministerial Council in 2012.

## 2. ILLUMINATION AND COMMUNICATIONS

The almost $90^{O}$ angle between the Moon's axis of rotation and the ecliptic means the lunar polar regions differ from the rest of the surface in that the local topography has an important influence on both the presence of solar illumination (note the Sun appears to move between only ~±1.5° around the horizon when viewed from near the south pole) and on the visibility of Earth. In these regions, specific locations of limited extent, at relatively high altitude compared to the surrounding terrain, could experience significantly increased durations of sunlight (several months) compared to the ~14 days illumination available at lower latitudes corresponding to the 28 day lunar month, while having only periodic (again ~28day cycle) visibility of Earth.

It is the potential for continuous periods of illumination which make the lunar polar regions so attractive for exploration missions, as well as the possibility of nearby dark craters which might act as cold-traps for volatiles and water-ice. Specifically for the Lunar Lander finding landing sites which experience several months of sunlight is key to the overall mission preparation, since this would determine the duration of nominal surface operations and define the specific needs in terms of landing accuracy in order to target such sites, hazard avoidance and darkness survivability.

As such the Lunar Lander project is conducting detailed studies of topographic data to assess the existence of such sites, analyse the availability of sunlight and direct-to-Earth (DTE) communications, and establish the physical size of those sites.

## 2.1 Illumination

Surface topographic data from the Lunar Orbital Laser Altimeter (LOLA) instrument onboard NASA's Lunar Reconnaisance Orbiter (LRO) is being used to assess both the size of preferentially illuminated sites as well as the temporal pattern of sunlight a lander would see at those sites. Similar analyses have been carried out by other groups on this new data-set[3,4].

The latest results show that the 'well' illuminated landing sites (i.e. those for which there is near-continuous sunlight for several months) are of very limited size, only in the order of 100's of metres, largely due to the fact that those locations represent local maxima in altitude and for which the surrounding terrain falls away relatively quickly. It has also been shown that the availability of illumination at those sites is strongly dependent on the observer height, particularly considering sun obscuration by close range obstacles such as local slopes and boulders[2]. Thus it is key that any illumination analysis performed in support of the definition of specific robotic operations ensures the height of specific elements (e.g. solar generators, antennae, radiators) is properly taken into account, even down to the metre level.

Illumination conditions at the landing sites have to be considered when assessing the performances of navigation and hazard detection and avoidance (HDA) systems for landing. The illumination conditions at time of landing, together with the optical properties of the surface, will impact the performances of the visual navigation sensors and ultimately of the navigation sub-system, which determines the absolute state of the lander (using landmarks) and the motion relative to the surface. On the HDA side, a shadowed terrain constitutes a hazard per-se, in that camera-based HDA is unable to detect hazards and to establish whether the terrain is safe to land on, although illumination might be present at the height of the lander.

It is important to bear in mind that while the latest LRO data sets are significantly more accurate than their predecessors, they are not without uncertainties. The effects of these uncertainties in terms of their influence on the confidence of the results, and margins which are required to account for them, is being investigated in the frame of the Lunar Lander project.

## 2.2 Communications

While sites around the South Pole offer the possibility to have near constant visibility of the Sun for long durations, this is acquired at the cost of continuous Earth visibility (at least for near-side sites). The ~5.5$^{O}$ inclination of the Moon's orbit about the Earth means that for polar sites >~85$^{O}$ latitude, the Earth dips below the horizon for up to 2 weeks each month.

The precise duration of these interruptions in Direct-to-Earth (DTE) visibility again depends strongly on the surface topography in the direction of the Earth and on the precise latitude and longitude of the site, however they can extend from 14 up to ~16 days, in a 28 day period.

It should be noted that while the patterns of communications and illumination availability can be determined in advance using surface data, they are in no way correlated: i.e. a site may experience illumination without communications, followed by periods of communications but in darkness. This has to be carefully addressed through analysis when considering surface operations. Also, the degradation of signal at low elevations, due to multi-path and interference effects, must be taken into account.

# 3. SURFACE HAZARDS

A landing hazard is a terrain feature that can cause the lander to crash or tip over if it lands on or over it. As such, steep slopes and, generally speaking, rough terrain features constitute landing hazards. In order to assess the risk associated to landing at the most promising sites identified by the illumination analyses, detailed studies based on LRO data have been performed[6,7].

The studies started with a review of the LRO data products. Then LOLA data was used to characterise the terrain slope, and LROC Narrow Angle Camera (NAC) images to detect craters and boulders and to collect the related statistics. It was found that LOLA data, although by far the most complete and accurate topographic data set of the Moon, is too sparse and inaccurate for slope assessment at the scale of interest, i.e. the lander footprint (~7 m). In any case, slopes over 50 m baselength are low (few degrees) at the sites, as can be expected from the conditions of favourable illumination. At smaller scales slopes should be mostly dominated by craters which can be expected to be mature (from geological context) and shallow (11 degrees from the rim to the bottom). Possible young craters could be identified in images thanks to their distinctive albedo signature.

Craters were detected in images down to a diameter of 1.5-2m, and their statistics (size-frequency distribution) collected, revealing generally an equilibrium distribution. Boulders were also detected, down to diameters of 1-2 m. In general, spatial distribution of boulders is non-uniform; boulders are sparse and grouped in clusters, if not absent (at some sites). Blocks of size smaller than 1 m are more difficult to detect, although it might be possible using the very long shadows cast in the presence of low Sun elevation.

Note that the analyses need to be iterated, especially with respect to slope assessment at small scales. It is necessary to analyse in more detail the combined sensitivity to slopes and low illumination angles of the crater and boulder size estimation accuracy. More information on boulder shapes needs to be collected. Note also that hazards posed by shadows have not been systematically analysed. Once candidate landing sites are confirmed by the illumination analyses, detailed analyses shall be performed in order to determine safety parameters for each site, such as the ratio of safe area to total landing area and the separation between safe areas.

## 4. KEY CHALLENGES

### 4.1 Guidance, Navigation and Control

The Lunar Lander mission scenario, as shown in the previous sections, poses several challenges to the design of the Guidance Navigation and Control (GNC) system. The major challenge involves the compliance of the end-to-end landing dispersion with the size of the areas suitable for surface operation durations of several months. As discussed earlier, such areas have a size of a few hundreds of metres. Moreover the system must also cope autonomously with the possible presence of hazards on the surface, therefore a Hazard Detection and Avoidance system (HDA) shall be available on-board. This system shall determine whether the pre-defined landing site is safe and, if not, reliably find an alternate site and command a re-targeting manoeuvre. The mission requires that the sum of the absolute GNC dispersion plus the maximum possible retargeting fits within a circle of 200 m radius (to be confirmed).

The navigation design is driven by the above requirements. Since early study phases, the need to use high altitude vision-based absolute navigation, along with relative visual navigation, has been identified. These advanced techniques will allow an improvement of the navigation performances, as compared to traditional techniques, such as inertial navigation and ground-based orbit determination. Furthermore, in order to guarantee soft landing and to reach the start of the approach phase within a tight corridor, a long-range altitude measurement is needed.

To validate the performance achievable with vision-based absolute navigation and verify the correct on-board implementation, breadboarding and testing has been foreseen very early in the Lunar Lander project, as described in the next section.

### 4.2 Vision-based Navigation

Absolute vision-based navigation generally consists of improving the position estimate by matching features or landmarks extracted from an on-board camera image with features contained in a database stored on-board. Techniques differ mainly in the type of features used, how these are matched and how the database is built. In general, these techniques can use both imagery and topographic data. Absolute navigation, however, poses several challenges related to the illumination conditions, to the generation of the feature database and to the on-board implementation.

In practice, vision-based navigation, if used from high altitudes, can potentially encounter highly varying illumination conditions, especially in order to limit the impacts at mission level. In particular, it will experience a large range of Sun elevation angles, and possibly large areas of shadow, generally degrading image quality and reducing the number of image features.

Concerning the generation of the database, and depending on the specific implementation and the required accuracy, challenges involve the spatial availability of features and the quality of the data sources. If images are used as the major source of features, to date the most accurate data comes from LROC NAC images (>0.5 m pixel size). Although the ultimate goal for the NAC team is to obtain a global coverage of the lunar surface by the end of the extended mission[9], most of the Moon has been mapped under a limited range of illumination conditions at this resolution. This can potentially reflect on large differences of illumination between reference and on-board images. This can impose severe constraints on the mission and requires a high robustness to the feature matching techniques with respect to illumination variations. Other datasets, such as LROC Wide Angle Camera (WAC) or Kaguya Terrain Camera (TC) images, have global coverage under highly varying illumination, but have lower resolution: WAC images cover the full Moon each month but have a resolution of ~70 m/pixel, whereas TC images present two illumination angles, also over the full Moon, with resolutions of ~10 m. For any dataset, the image quality degrades near the poles, corresponding to the last phases of landing, due to poor illumination.

Digital Elevation Models (DEM’s) of the lunar surface are also used in the databases, either alone to extract features, or to provide the third dimension to image features. LOLA DEM's offer a good coverage (~1 km separation between tracks at the equator down to few tens of metres near the poles, and still improving with time) with very good position accuracy, but suffer mainly from the presence of artefacts. Kaguya provides both global laser altimetry data and stereo-based terrain models, with virtually ~10 m resolution, which degrades near the poles again due to poor illumination.

For all datasets, the characterization and correction of the map-tie error, i.e. the error in referencing a feature contained in the data with respect to a coordinate system attached to the Moon, is a process that requires a dedicated quality control. As of today, it is estimated that both LRO and Kaguya datasets suffer from a map-tie error of few tens to hundreds of metres[5,8]. However, this is being improved with time, with the LOLA dataset being used as new control network. In the near future, the GRAIL mission will improve the knowledge of the lunar gravity field and therefore the orbit solutions attached to the current datasets. Besides, the database generation process needs to be validated.

In terms of on-board implementation, image processing functions generally involve heavy computational loads, and are likely to require dedicated processing resources. Furthermore, matching descent camera image features with features from the database can also be demanding, depending on the specific implementation. However, commonalities with other Navigation functions might be used in order to reduce the overall data processing need.

### 4.3 Altitude Estimation

Generally, the initial Approach phase conditions must be reached by the lander within a tight corridor, in order to guarantee safety and good visibility of the landing site for hazard detection. Considering the limited altitude estimation performances based on visual navigation only, a direct range measurement is required. However the altitude estimation is affected by the terrain characteristics at and up-range of the landing site. At the South Pole the terrain elevation can vary by several hundreds of metres up to a few kilometers, within a few kilometres of the potential landing sites.

As an example, Figure 2 (top) shows the terrain around the pole, with a theoretical approach track (~20 km up-range): the difference between the landing site altitude and the terrain altitude along the track can be up to 3 km (bottom). If the pointing of the range sensor is unconstrained, this difference will be seen as a bias to the actual landing site altitude. Solutions to this issue include correlating the range measurement to a reference DEM carried on-board, by using the position and attitude estimation, or constraining the trajectory and attitude profile to point the range sensor beam towards the landing site. Besides, terrain variation at the site and lunar surface characteristics may also affect the accuracy of the range measurement.

### 4.4 Hazard Detection and Avoidance

The HDA system must be able to detect hazards on the surface at the landing site and if needed command a retargeting towards another safe landing site, respecting vehicle constraints such as propellant usage and maximum attitude deviations. Both a camera and an imaging LIDAR can be used in order to build hazard maps. Such maps must be fused, along with mission-dependent maps (propellant, visibility etc.) in order to obtain a global safety map. As a compromise between expected hazard detection performances, lander touchdown stability envelope and clearance and knowledge about the terrain, the criteria to define a site as safe have been identified as mean slope (over the lander footprint) of 15 degrees and roughness (deviation from the mean terrain) of 50 cm. The requirements on the HDA system stem from this, both in terms of detection performance and divert authority.

The major challenge for the HDA system is again related to the special illumination of the prospective landing sites, which makes images dark and patchy. To get over the limitations of camera-based hazard detection, an imaging LIDAR may be used. However, imaging LIDAR's often build an image of the terrain through a scanning mechanism, therefore the motion of the lander must be compensated. This poses constraints on the stability of the lander during image acquisition, on the accuracy of the velocity and attitude estimates used to correct the image and on the required processing power.

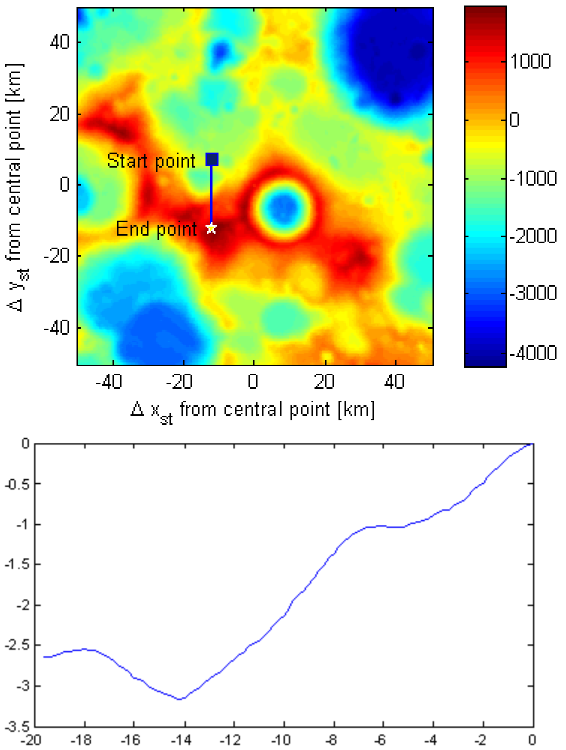


Fig. 2. Terrain around the pole (altitude in metres), with a theoretical approach track (left); terrain variation relative to landing site in km, along the track (right).

### 4.5 Guidance and Control

The main driver for the lander Guidance and Control design is the need to optimise the reference trajectory and the trajectory tracking, while complying with visibility constraints, particularly during Approach. The major challenge comes from the need to comply with high precision position and attitude control requirements while using the available propulsion system, which is composed of a set of fixed-thrust, main engines, a set of pulsed assist engines and possibly the Reaction Control System (also used for cruise). The solution generally adopted is to use the pulsed engines to provide controllability (for both position and attitude or for position alone), but still the thrust profile must be designed to avoid re-ignition of the main engines, including margins to compensate errors and initial mass variations.

Moreover, the control system must cope with potentially significant disturbances due to propellant sloshing (although anti-sloshing devices may be included in the tank design to reduce the effect of sloshing, in combination with propellant settling manoeuvres). This might be challenging when considering possible limitations of the Pulse Modulation Frequency of the assist engines and coupling with the natural sloshing frequencies. Besides, the G&C function must cope with the expected performances of the propulsion system, which are mainly driven by the combination on the same feed lines of high thrust engines shutting down and assist engines being pulsed, and the subsequent expected thrust fluctuations.

### 4.6 Propulsion

Following the trajectory established to achieve a landing on the Moon, in a fuel efficient way, requires the lander to be able to apply different levels of thrust at different points during the landing. A high thrust during the main braking phase must be modulated to progressively lower levels of thrust as the lander approaches the landing site. Variability of this lower thrust level is also required in order to allow the lander to precisely control its trajectory and guide itself towards the landing site based on inputs from the navigation sensors and systems. Thrust variability can be achieved through the use of throttleable engines, as in the case of the Apollo descent module. However the unavailability of such hardware in Europe has directed the Lunar Lander project down the alternative path of achieving thrust variability through the use of pulse modulation, i.e. rapidly pulsing engines on and off to achieve the desired net thrust.

The approach followed by the Lunar Lander, using multiple fixed thrust main engines combined with a number of pulse modulated assist engines, clearly adds complexity w.r.t a single throttleable engine solution. Operating such a cluster of thrusters in close physical proximity and from the same unique fuel system raises specific challenges such as hydraulic cross-talk between engines and the thermal impact of one engine upon another. Compatibility in terms of control between the engine cluster and the GNC is also a key issue which must be addressed early in the project to ensure the designs of both GNC and propulsion subsystems are properly coordinated.

Issues associated with the large number of engines operating in parallel (e.g. cross-talk) as well as engine behavior in pulse mode have been the subject of recent breadboarding and testing carried out in the Lunar Lander project, described in the next section.

### 4.7 Surface Survival

Operating on the lunar surface, at most locations not in the polar regions, for durations exceeding 14 days implies surviving the dark and extreme cold associated with the long lunar night. Several past lunar missions, like other planetary missions, have used radio-isotope devices as a reliable source of heat and/or electrical energy to get through these challenging periods. Europe’s space missions however have not had access to such technologies due mainly to their non-availability in Europe and then complex procedures required for working with and launching such devices. While activities investigating the development of radio-isotope heating units (RHUs) and ultimately radio-isotope thermoelectric generators (RTGs) are proceeding within Europe, it is not expected that European devices would be available in the 2018 timeframe of the Lunar Lander mission.

Avoiding the use of such devices may be possible by exploiting the unique illumination conditions near the Lunar poles, where topography and orbit combine to leave some locations illuminated for up to several months at a time. This is one of the primary reasons for pursuing a south polar landing site for the Lunar Lander mission, thus allowing for a design without radio-isotope devices.

However, it is not guaranteed that a mission operating at these sites will not experience some, perhaps significant, periods of darkness. Without either RHUs or RTGs the lander is entirely reliant on stored electrical energy to get through any darkness periods, which in the case of the Lunar Lander translates directly into battery mass.

Minimising the amount of energy required to ensure the survival of equipment and any limited operations required during dark periods requires a careful optimization of the combined power and thermal sub-systems of the platform. Pushing down the lower limits of temperature which the most sensitive equipment can survive (e.g. electronics, battery) as well as improving and optimizing their thermal insulation can allow the lander to endure longer periods of darkness before having to actively heat. The current configuration of the lander employs a Central Avionics Bay (CAB) in which the most sensitive components are housed allowing an optimum temperature control throughout the lander. The efficiency of thermal subsystem hardware such as thermal switches and loop heat pipes (LHP) also plays a major role in extending the survivability of the lander.

## 5. PROJECT STATUS

### 5.1 Phase B1

Early Phase B activities have been initiated in August 2010 following Phase A studies which analysed a range of mission options. In April 2011 a major milestone in the form of a Polar Landing Review (PLR) took place in which both the mission and spacecraft design were scrutinised as well as the quality and results of analyses into the lunar surface illumination conditions. Based on the outcomes of this review, Phase B activities are continuing with a consolidation of the mission and system design as well as more detailed investigations surrounding landing sites and the conditions they offer. Phase B1 shall be concluded in autumn 2012.

### 5.2 Breadboarding Activities

The Lunar Lander builds on a foundation of technology development already initiated in 2005/2006 within the Aurora Core Programme, which has matured a range of key technologies relating to soft precision descent and landing with hazard avoidance. These technologies are being further advanced within the Lunar Lander project which, within the Phase B1, places a particular emphasis on hardware breadboarding activities.

*Pulsed Engine Hot-Firing*

The Lunar Lander project has selected the so-called 220N ‘ATV’ thruster (so-called because of its use as attitude control thruster on ESA’s Autonomous Transfer Vehicle series) as the baseline assist engine. Six such engines shall be combined with five 500N main engines, and shall be operated in pulse modulated mode during descent and landing to realise the overall thrust modulation required.

Breadboarding activities have been carried out as part of the Lunar Lander project to investigate this engine’s performance and behaviour when operated at the frequencies requested by the mission’s GNC, which are higher than previously tested with this engine. These tests involved hot-firing of a single thruster in a test chamber under a variety of pulsed and steady state conditions (see Figure 3).

The overall results of this testing showed that the 220N ATV thruster demonstrates very robust performance across the range of operating frequencies demanded by the Lunar Lander. Testing also confirmed the thermal behaviour of the engine under pulsed and steady-state conditions, and the compatibility of this behaviour with the Lunar Lander at system level.

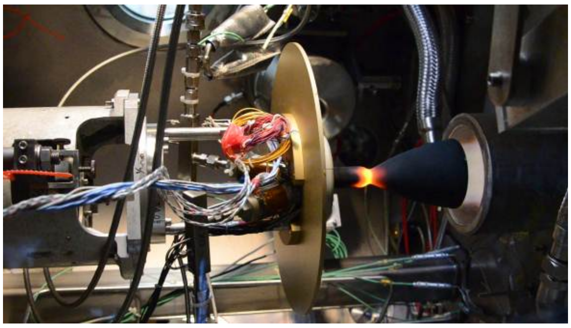

Fig. 3. Hot-firing testing of 220N engine in pulse mode, carried out at Astrium Lampoldshausen.

*Propulsion Subsystem Hydraulic Model*

The Lunar Lander propulsion subsystem combines a significant number of individual engines of different types, operating together during the descent and landing phase. This configuration, selected in order to stay with European propulsion technologies, raises a number of potential issues relating to the behaviour of the overall propulsion sub-system.

To investigate these issues, the Lunar Lander project has performed the construction and testing of a propulsion subsystem hydraulic breadboard. This setup (see Figure 4) provides a representative assembly of components (valves, tubing etc.) with the flow characteristics of the engines represented by combinations of valves. Water replaces the fuel and oxidiser as the fluid medium.

Tests on this hydraulic breadboard have been carried out to investigate overall pressure drop within the system, particularly during the firing of all main engines, as well as effects of thruster cross-talk on the pressures seen at the inputs to the engines. The results of these tests are being used to validate software models in EcoSIM, which may then be used to investigate the propulsion sub-system behaviour in more detail.

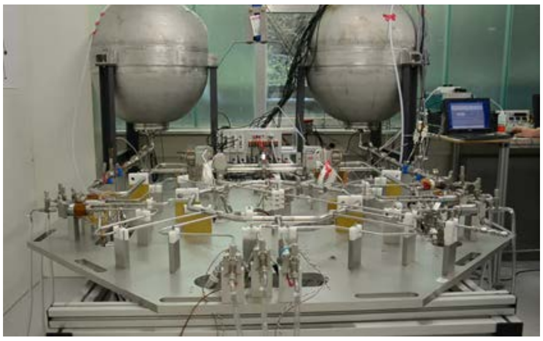

Fig. 4. Lander propulsion system hydraulic breadboard (fluid side) at Astrium Lampoldshausen.

*Navigation Breadboarding*

The validation of vision-based navigation techniques is a critical step in the demonstration of the end-to-end GNC performances, and is being achieved in a step-wise approach, using computer generated images and real orbital images. The next step is the test of the full functional chain involved in absolute optical navigation in a laboratory environment.

The Testbed for Robotic Optical Navigation (TRON), located at the DLR-RY institute in Bremen, is being prepared and will be used for these tests. The facility consists of: a set of scaled lunar terrain models manufactured on the basis of realistic surface structures and wall-mounted; a camera, mounted on a 6-degree of freedom robotic arm which moves on a rail to simulate scaled lunar descent trajectories; a dedicated lighting system to simulate planetary illumination conditions; all the necessary software and hardware tools for test set-up and post-processing of the data.

The objective of this activity is to validate, in a realistic environment and using real hardware, the performances of the absolute navigation, including the image processing function and the navigation filter, from the generation of the landmark database to the simulation of the operations of absolute navigation during a complete descent.

*Avionics Breadboarding*

To increase the technology and integration readiness level of critical subsystems of the lunar lander such as avionics and GNC, a flight representative avionics demonstrator has to be developed and used for the validation of the GNC embedded software, including terrain navigation image processing and Hazard Detection and Avoidance (HDA) algorithms. It is planned in the frame of the Lunar Lander Phase B1 to develop the critical building blocks of the avionics system and to integrate them with procured hardware in a global avionics/GNC test bench. A first real-time performance test campaign will also be conducted.

Further breadboarding activities are envisioned in the fields of thermal sensitivity and thermal control to support the design of the lander in terms of darkness survivability. Extending this hardware work to other critical elements and subsystems is a major goal of the follow-on Phase B2.

### 5.3 Next Steps

While the Phase B1 shall continue up to autumn 2012, along with the highest priority breadboarding activities, the programmatic framework for the continuation of the project shall be prepared via the ESA Council at ministerial level due to take place in November 2012. The Council meeting is the primary financial decision point for ESA programmes, taking place approximately every 3 years. The Lunar Lander project shall seek the financial resources to continue the design and hardware work beyond 2012 with Phase B2, and ultimately C/D/E activities. As an optional programme within the broader human spaceflight framework the Lunar Lander project shall seek to continue to expand the numbers of participating ESA Member States to exploit the full breadth of industrial experience existing in Europe.

## 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 Lunar Lander, those challenges can be practically addressed step-by-step. The European Lunar Lander seeks to take the next step, as a precursor mission, demonstrating the key capability of soft precision landing with hazard avoidance and as one of the first in-situ explorers of this complex and challenging environment.

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