UK Lunar Science Missions: MoonLITE & Moonraker

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Summary

Surrey Satellite Technology Ltd. (SSTL) and Surrey Space Centre (SSC) have been preparing a 'smallsat' approach to achieving a low-cost lunar mission for more than a decade – including various activities, such as the earlier ESA study on LunarSat and currently hardware contribution to the Chandrayaan-1 mission. With the recent successes in GIOVE-A, TOPSAT & BEIJING-1, alongside participation in Aurora & Chandrayaan-1, Surrey have developed capabilities for providing affordable engineering solutions to space exploration. SSTL/SSC was recently funded by UK Particle Physics and Astronomy Research Council (PPARC) to undertake a study on low-cost lunar mission concepts that could address key scientific questions. This paper presents some key results from this study [1] and provides preliminary definitions of two down-selected mission proposals.

2 Introduction

Since the last Apollo landing 35 years ago, our knowledge of the Solar System has expanded immeasurably, bringing us up against questions that are impossible to be answered on Earth. There is now a global renewed interest in returning to the Moon, driven both by the demands of science and as a stepping-stone for human exploration of the Solar System [e.g. 2, 3]. In terms of science, the Moon provides a *unique* record of processes affecting evolution of terrestrial planets during the first Giga-year or so of Solar System history. This includes internal processes of geological evolution (e.g. differentiation and crust formation) and external processes caused by the environment (e.g. meteoroid and asteroid flux, interplanetary dust density, solar wind flux and composition, galactic cosmic ray flux) that are not as easily examined anywhere else in our solar system. So far, all the in situ measurements of the lunar surface have been obtained by soft landings on the near side of the Moon, mainly from Apollo, Luna and Surveyor missions.

Actual samples have been returned from only 9 locations from mid to low latitudes on the near side, including the 6 Apollo and 3 Luna landing sites. There is little doubt that returning to the Moon could, with sustained effort, vastly enhance our knowledge of the Solar System and of our own planet. The UK already plays a significant role in lunar science research by participating in the Clementine, SMART-1, Chandrayaan-1 and LRO missions, as well as through geological studies using remote sensing and lunar meteorite data as inputs to theoretical modelling. These place the UK in a position to play a major role in the next steps of lunar exploration.

During 2006, PPARC funded SSTL to carry out a pre-phase-A study of a UK-led small-scale lunar mission. A fundamental driver in the study was that any UK-led mission must be (1) affordable, whilst (2) satisfying key science objectives not yet addressed and (3) offering the opportunity for educational outreach and (4) stimulating the UK industrial capability in space exploration. The study assessed the scientific and technological requirements of three baseline mission options, namely orbiter, lander and sample-return. The design and cost drivers in terms of science performance and required technology were identified. First-level system design and trade-offs were performed. Finally, two mission proposals were established namely MoonLITE and Moonraker. This paper presents a preliminary mission definition, including the science & technology, of the two mission concepts, as well as a science comparison with forthcoming approved missions. This study also opens a discussion on ways of enhancing the UK's contribution by strategic partnering with other nations also interested in pursuing affordable lunar exploration.

3 MoonLITE (Moon Lightweight Interior and Telecom Experiment)

3.1 Mission Rationale

The MoonLITE mission concept comprises a small orbiter and four penetrators (see Figure 1). The orbiter will demonstrate communications and navigation technologies aimed at supporting future exploration missions, whilst the primary scientific goal is to investigate the seismic environment and deep structure of the Moon including the nature of the core, by placing a network of seismometers via penetrators on the lunar surface. The four penetrators would be widely spaced over the surface, with a pair on the near side (a preference for one being in the same area as an Apollo landing site) and the other pair on the far side. In addition, heat flow experiments will be conducted. If possible, one penetrator would be targeted at a polar cold trap and equipped with a sensor to detect water or other volatiles. The surface mission is proposed to last 1 year supporting the seismic network. Other science experiments do not require so long (a few lunar cycles for heat flow, and much less for volatiles). Provision for penetrator descent imagery would be desirable for both science context and outreach purposes.

The demonstration of airless (i.e. non-aerodynamic) instrumented penetrators on impacting the Moon would prove a technology relevant to the scientific exploration of other high priority planetary destinations such as Mercury, Europa and Enceladus. UK interest in penetrator technologies has been gathered into a national consortium comprising major academic and industrial players: MSSL, Surrey, The Open University, Birkbeck, QinetiQ, Imperial College and Southampton.

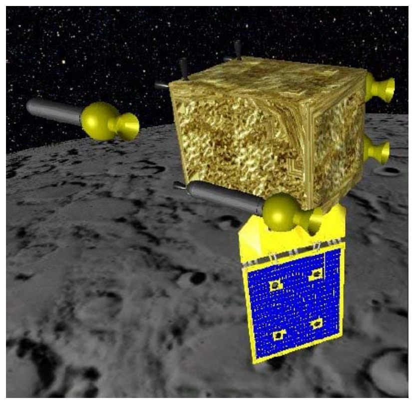

Figure 1: MoonLITE orbiter carrying four penetrators

The primary purpose of the orbiter after the deployment of the penetrators is to provide telecommunications relay for penetrators and to demonstrate high-rate communication links from the lunar surface. It would be a pathfinder for a permanent high data rate lunar telecommunications infrastructure operating at Ku band (as anticipated in NASA and ESA long term requirements for lunar exploration). As far as possible, the telecom capability should be compatible with other lunar orbiters and NASA’s planned robotic landers. If feasible, some form of navigation payload might also be included. These aspects of the mission concept offer opportunities for bilateral or multilateral cooperation and cost sharing.

3.2 Mission Profile

MoonLITE is technically compatible with a launch in 2010-2011 and to operate on the lunar surface for 1 year. In order to minimize trajectory ΔV requirements and hence launch costs, a direct injection into Trans-Lunar Orbit (TLO) by PSLV[1] is used as baseline (although other launchers will be considered for the final mission). A transfer trajectory that combines a low ΔV (reduced propulsion system costs), short Earth-Spacecraft distances (simpler communications system)

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[1] Although it has not been possible to establish the precise capacity of PSLV for insertion into TLO, a launch mass limit of 810 kg is assumed.

and short transfer times (lower operations cost during transfer) is desirable. After considering a number of possibilities (e.g. direct transfer, bi-elliptic transfer and weak stability boundary transfer), we chose a direct transfer trajectory to the final lunar orbit, as illustrated in Figure 2. This transfer takes about 3 days. The final orbit is set to be a 100 km circular polar orbit because it provides a sensible balance between orbiter/penetrators ΔV requirements and the visibility of the penetrators for data relay purposes. The proposed total ΔV budget including mid-course correction, lunar orbit insertion and orbit maintenance for a 1-year mission is 1217 m/s with adequate margins.

For penetrator deployment (see Figure 2 right), an initial manoeuvre places the penetrator on a trajectory with periapsis near the lunar surface (40 km altitude for example). A large second burn is performed to slow the penetrator down to near zero velocity to allow it to drop to the surface. Additional attitude control manoeuvres are required during the final drop to the surface to ensure the penetrator impacts the lunar surface vertically.

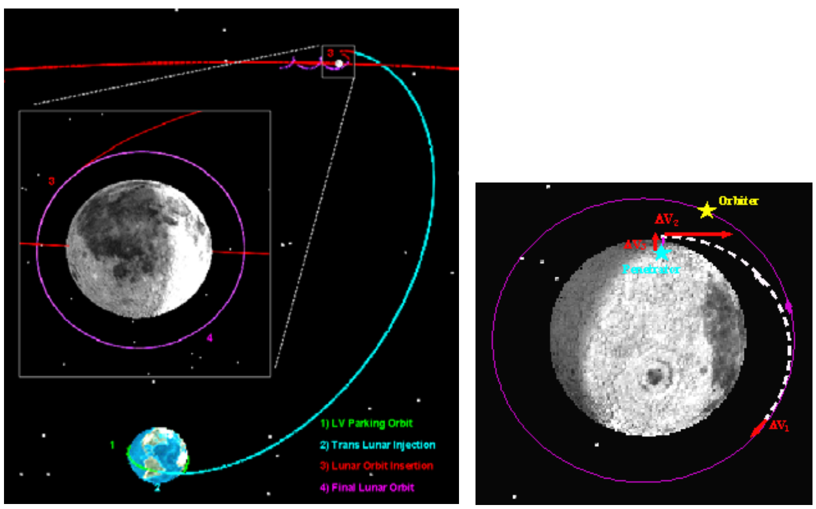

Figure 2: Orbiter transfer trajectory (left) and penetrator deployment trajectory (right)

3.3 MoonLITE Spacecraft

The basic configuration of the MoonLITE spacecraft is shown in Figure 3. The concept is based on GIOVE-A spacecraft but only one solar array is required, which remains stowed until after penetrator deployment and then it rotates.

The four penetrators are attached in two pairs on opposite sides of the orbiter body. Each cylindrical penetrator is to carry and deliver a science payload (e.g. seismometer, heat flow probe and volatile detector) to the lunar surface. The design baseline is similar to the Japanese Lunar-A penetrator. Each is assumed to have a total mass budget of 36 kg - including 23 kg of propulsion and 13 kg of actual penetrator carrying a science payload mass of ~3 kg. The penetrator is expected to impact at the lunar surface around 300 m/s. Data rate from the penetrator to the orbiter is assumed to be 30 kbits per day. The UK penetrator consortium is currently investigating the some key design and development issues.

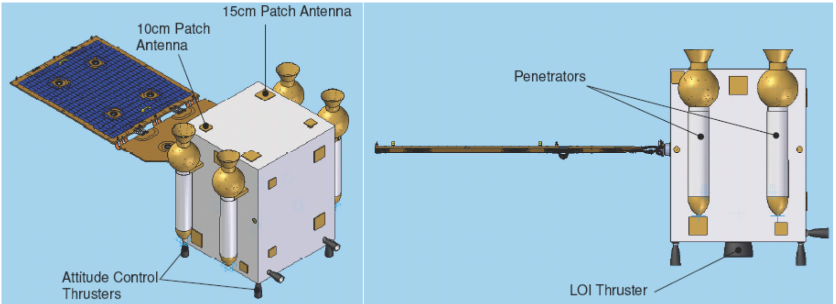

Figure 3: MoonLITE spacecraft configuration

The spacecraft contains low and medium gain antennas (10 and 15 cm patch) on all faces to provide omi-directional communication coverage. The orbiter has two S-band ranging receivers (0.5-4 kbps using a 10 cm patch antenna) and transmitters (0.4-2 kbps using a 15 cm patch antenna) for communication with Earth ground station[2] and penetrators. To provide uplink at high speed for other surface activities on the Moon, the orbiter is also equipped with one Ku-band receiver (10 Mbps using an omni directional antenna).

A chemical propulsion system is adopted based on a bipropellant solution using MMH and NTO that gives the most mass efficient solution[3]. A single centrally-mounted 400N or 500 N thrust engine (see Figure 3) is used to perform the main ΔV manoeuvres. Four 10 N thrusters, located at the corners of the same panel, are used for attitude control during the orbit manoeuvre firings. Together with two others on the side, all thrusters would be used for the full range of attitude control functions during the mission.

Attitude determination is performed using sun sensors and star cameras, combined with three-axis gyros utilized during manoeuvres. Three-axis attitude control is executed using four orthogonal reaction wheels and a set of 12 redundant thrusters. The on-board propulsion system mentioned above is used for control during orbit manoeuvres and wheel de-saturation.

3.4 Mass Budget

[2] The Earth ground station baseline is the Rutherford Appleton Laboratory (RAL) 12 m aperture antenna

[3] SSTL is developing a bipropellant engine using hydrogen peroxide (HTP) and kerosene that would potentially reduce the recurring costs further.

The mass budget of MoonLITE is shown in Table 1 (left). The total launch mass is 846 kg. Further mass reduction trades are being explored to reduce the orbiter mass to match the performance of the PSLV.

MoonLITE Mass Budget (kg)	
Structure	131.0
Communications	8.4
Power	28.7
Solar Panels	15.3
AOCS	44.1
Propulsion	66.1
OBDH	6.5
Environmental	16.6
Harness	30.0
Payload (penetrators & navigation payload)	158.4
System Margin (platform)	34.7
Total (Dry)	**539.7**
Propellant (Transfer, LOI, OM)	296.4
AOCS Propellant	10
Propellant (Total)	**306.4**
Total (Launch)	**846.1**

Moonraker Mass Budget (kg)	
Science Payload	**23.6**
TTC Comms	19.1
Structure	45.1
ADCS	14.7
OBDH	4.3
Power	9.4
Propulsion (hydrazine)	30.8
Harness	9.9
Thermal Control	3.1
Landing Gear	16.2
System Margin	17.6
Lander (Dry)	**193.8**
Descent liquid propellant	58.0
Lander (Total)	**251.8**
Solid motor stage	493.3
Liquid propellant during cruise transfer	28.1
Propellant (Total)	**521.4**
Total (Launch)	**773.2**

Table 1: Mission mass budgets for MoonLITE and Moonraker

4 Moonraker

4.1 Mission Rationale

The Moonraker mission consists of a single propulsive soft-lander (see Figure 4) aiming to provide a low-cost European lander capability for extensive robotic exploration of the lunar surface in preparation for subsequent human expeditions. The first mission is targeted to the lunar near side, which allows direct-to-Earth communications. The primary science goal is in situ dating of the young basalts at northern Oceanum Procellarum, both for understanding lunar evolution and for better calibrating the lunar cratering rate that is used with assumptions for dating solid surfaces throughout the whole Solar System. The envisaged in situ method involves a K-Ar dating technique being investigated at the University of Leicester and the OU. This combines data from both X-ray spectrometer and mass spectrometer derived from Beagle 2 and Rosetta heritage. This technique is at present un-proven (even controversial). Discussion is ongoing among UK instrument and science experts to seek consensus on whether this approach is sufficiently robust to at least be worth testing on a small mission. If successful, the approach could be of general use at other rocky planets, and could be used to help select samples for return-type missions (e.g. Mars Sample Return). Should this not be the case, the instrumentation derived from Beagle 2 would also be suitable for general geochemistry work, which would also be scientifically very valuable if performed at sites from which samples have not yet been returned.

Technologically, the robotic lander could embody greater intelligence than ExoMars (e.g. vision-based guidance for the terminal phase) to allow landing autonomously on the ejecta blanket of a suitable crater such as Lichtenburg. This capability would be novel but is essential for future precision robotic landers (Mars, asteroids, Europa, etc). Work on such technology is being undertaken in the technology studies within the ESA Aurora programme, and several UK companies and laboratories are already involved. Surface sample acquisition may involve robotic arms, miniaturized drills, possibly including a 'rake' to extract small rock fragments of interest from the regolith, giving rise to the mission name, 'Moonraker'. The mission concept could be implemented either through bilateral, multilateral cooperation or via Aurora as an MSR precursor mission, driven by the need to test vision-based precision terminal guidance using active hazard avoidance.

Figure 4: Moonraker landed on the lunar surface

4.2 Mission Profile

Moonraker is proposed to launch in 2013. The spacecraft is placed directly into a trans-lunar orbit by the PSLV launcher. A direct hyperbolic approach is used to land on the northern region of Oceanum Procellarum, where has direct visibility to the Earth. This transfer duration is approximately 5 days. The entire transfer trajectory is shown in Figure 5 that illustrates the direct interplanetary transfer, hyperbolic arrival and final descent to the surface. The descent phase starts with a spin-stabilised solid motor firing to decelerate the approach velocity from 2.5 km/s when the lander is about 70 km above the surface. It takes less than 1 minute for the lander to reach 10 km above the surface and velocity to be reduced to about 80 m/s. The lander then jettisons the solid motor, fires the liquid motor and continues to decelerate. From this point until landing, the target duration is 4 minutes. The lander subsequently enters despin & transitions to a 3 axis stabilization mode, followed by a 3 axis controlled descent mode, a free fall in the last few metres, and finally terminates with an impact at ~3 m/s. The surface operating lifetime is about 3 months (i.e. 3 lunar days).

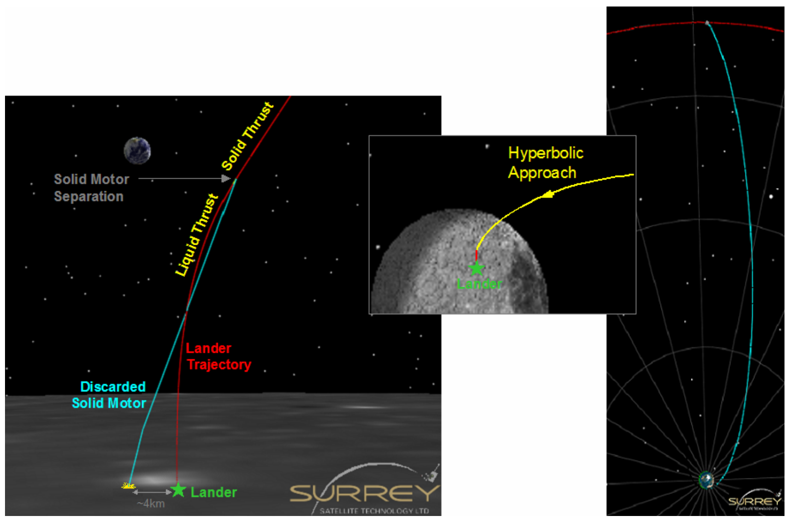

Figure 5: Lander trajectory

4.3 Moonraker Spacecraft

The Moonraker spacecraft is configured as shown Figure 6. A hexagonal structure is selected, providing facets for the landing gear and for 3 solar panels. The solar panels are deployed once on the surface, their angles being set to optimize solar power generation once the orientation of the lander on the surface has been established. There is generous internal volume for accommodation of the lander avionics, power conditioning and science instruments. The baseline science instruments include XRF spectrometer, multispectral imaging system, Raman/LIBS, seismometer and heatflow probe. The sample acquisition equipments would be mounted on the underside of the lander. The total science payload including sample acquisition package is estimated less than 22 kg.

The top facet provides support to the 50 cm diameter parabolic high gain antenna used for transmission of science data direct to Earth. There are also 10 cm and 15 cm patch antennas mounted on the top offering omni-directional communications coverage. One S-band receiver (4 kbps & a 10 cm patch) and transmitter (2 kbps & a 15 cm patch) are used for TT&C with Earth ground station. An S-band transmitter of 38.4 kbps is used to transmit the science data back to Earth.

The baseline concept for the propulsion system is to use a solid motor (e.g. ATK Thiokol’s STAR 30BP) to provide 84% of the total deceleration ΔV. The remaining deceleration, trajectory correction and targeting, spin-up/despin and attitude control velocity increments are provided by a liquid propulsion system. The hydrazine blowdown monopropellant system used comprises two 60-litre propellant tanks each containing ~86 kg hydrazine, filters, latch valves, pressure transducers and 3 identical thruster modules, one on each leg. Each thruster module has a nominal 150 N engine for deceleration and three 20N nominal engines for spin and down, attitude control and lateral movement. For reliability and robustness, each thruster has redundant valve seats.

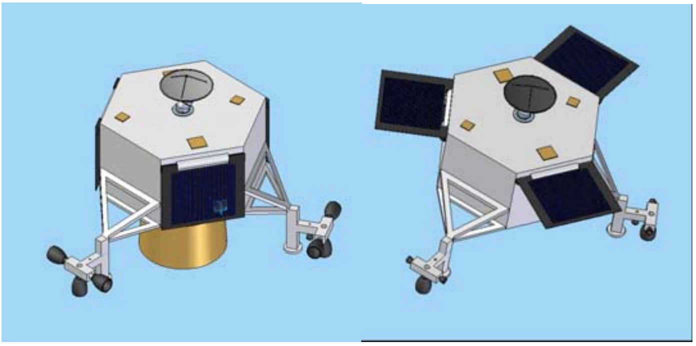

Figure 6: Moonraker spacecraft configuration: cruise (left) & on-surface (right)

Attitude determination is performed using sun sensors, a star camera, a three-axis Inertial Measurement Unit (IMU) and an Earth and Sun Sensor (ESS)[4]. AOCS actuation is provided by monopropellant thrusters.

4.4 Mass Budget

The mass budget of Moonraker is shown in Table 1 (right). A margin of 10% has been added to the science payload mass presented earlier and a 10% overall system margin is included. The overall launch mass of 773 kg is within the capacity of the nominal PSLV launch vehicle including an allowance for the launch vehicle adaptor.

5 Future Missions Science Comparison

Science	SELENE	Chandrayaan-1	Chang’e I	LRO/LCROSS	Moon LITE	Moonraker	RLEP2	Luna-Glob
Image mapping	x	x	x	x				

[4] Radar and/or vision package using modern technologies can be further investigated to improve the performance of gravity turn descent.

Gravity mapping	x							
Radiation field	x	x	x	x				
Topography mapping	x	x	x	x				
Mineralogical composition	x	x				*		
Chemical element composition	x	x	x			*		
SPA water detection	x	x	x	x *	*		*	*
Basalts age dating						*		
Seismometry					*	*		*
Heat flow					*	*		

x Remote sensing; * Surface in-situ

6 Conclusion

The Moon remains scientifically appealing and has generated revived interest in recent years [e.g. 3]. Despite the large number of planned missions, there still remain significant gaps in science that can be addressed by low-cost UK-led lunar missions. Small, low cost missions have become highly successful in recent years, with outstanding results and many scientific and commercial users. The capabilities of small satellite have also seen drastic improvement, and have matured to the point where such missions offer huge potential within space exploration. In previous centuries, nations and groups participating in exploration have gained significant economic benefits, and leadership and a modest investment in space exploration now can position the UK as a key player in this area. The MoonLITE and Moonraker missions provide a stepwise approach to space exploration, using the Moon as a proving ground for technology that is essential for robotic exploration of Mars and de-risking larger programmes such as ExoMars and MSR. In addition, the mission scientific objectives provide a platform for UK science community to remain a leading player and better position itself for international collaborative missions.

Acknowledgement

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References

[1] A. Phipps, Y. Gao, et.al. Lunar Mission Option Study, UK Particle Physics and Astronomy Research Council, Reference No. #118537, pp. 1-104, (Nov. 2006).
[2] Crawford, I.A., The Scientific Case for Renewed Human Activities on the Moon, *Space Policy*, 20, 91-97, (2004)
[3] Bradley L. Jolliff, Mark A. Wieczorek, Charles K. Shearer, and Clive R. Neal, eds., New Views of the Moon, *Rev. Min. & Geochem.*, 60, (2006).