Return to the Moon — a UK Perspective

Summary/Abstract
The rationale for UK participation in robotic and human missions to the Moon is assessed. The science objectives are found to be strong, as is the use of the Moon as a test-bed for exploration beyond the Earth–Moon system. UK and international initiatives are reviewed, showing that the UK has extensive expertise to bring to bear. Recommendations for action by UK government are presented including the need for a sustainable programme of missions rather than a one-off, and the benefit of UK leadership of discrete and critical elements of any lunar project in order to attract public support.

List of abbreviations
- BNSC: British National Space Centre
- CNSA: China National Space Agency
- ESA: European Space Agency
- IR: Infra-Red
- ISRO: Indian Space Research Organisation
- ISS: International Space Station
- JAXA: Japan Space Agency
- K-Ar: Potassium-Argon
- kbps: kilo bit per second
- LROSS: Lunar Crater & Observation Sensing Sat
- LIDAR: Light Detection And Ranging
- LRO: Lunar Reconnaissance Orbiter
- MMH: monomethylhydrazine
- MSR: Mars Sample Return
- NASA: National Aeronautics and Space Administration
- NTO: Nitrogen tetroxide (N2O4)
- OU: Open University
- PPARC: Particle Physics & Astronomy Research Council
- PSLV: Polar Satellite Launch Vehicle
- RAeS: Royal Aeronautical Society
- SEWG: Space Exploration Working Group
- SPA: South Polar Atken
- SSTL: Surrey Satellite Technology Ltd
- TT&C: Tracking Telemetry & Command
- UK: United Kingdom
- VLBI: Very Long Baseline Interferometry
- VRA/D: VLBI RADio

1.0 Introduction
1. Prior to the space age, the origin of the Moon was the subject of wide debate, with several theories under consideration. The analysis of lunar rocks brought back by the Apollo astronauts and to a lesser extent by the three Soviet Luna sample return missions broadly resolved that question[1]. Those missions mapped the Moon in detail including on the farside that is hidden from Earth-bound observers. Then from the last Luna mission in 1976 there was an 18-year gap until the 1994 US Department of Defense Clementine mission followed in 1998 by the NASA Lunar Prospector — both of which went into lunar orbit. There has been sporadic interest in lunar missions since then, but generally speaking scientists have found other solar system destinations more interesting — Mars still has many secrets to reveal, while we have barely scraped the surface, scientifically speaking, of the other planets and their hordes of moons.

2. In the past few years, the Moon has again become a priority destination for the world's space agencies. Driven by a mix of scientific interest and the exploration imperative, the European Space Agency (ESA), China, and Japan have initiated Moon-bound missions, with Indian and American missions due for launch in 2008. The scientific motivation is to seek answers to questions about the history and make-up of the Moon. The exploration motivation is not only to explore the Moon itself but to use it as a cost effective test-bed for techniques and technologies to explore Mars and other bodies of the solar system. A global exploration agreement has been signed by 14 of the world's space agencies, in recognition of the benefits of collaboration in pursuit of these challenging objectives[10].

3. ESA's SMART-1 spent the three years from November 2004 surveying the Moon's surface using optical, infra-red (IR) and X-ray instruments. It was then deliberately smashed into the lunar surface so that observers could analyse the debris ejected by the impact and thus learn more about the mineralogy of the impact area — NASA's Lunar Prospector had performed a similar end-of-life manoeuvre in 1999. The Japanese Space Agency (JAXA) Kaguya (formerly called SELENE) mission was launched on 4 September 2007 and entered lunar orbit three weeks later. It consists of three satellites, an orbiter containing most of the scientific equipment to survey the Moon obtaining data on elemental abundance, mineralogical composition, topography and geology, a VLBI (Very Long Baseline Interferometry) Radio (VRA/D) micro-satellite, and a relay micro-satellite.
design to receive a doppler ranging signal from the orbiter when it is around the far side out of direct contact with the Earth and transmit the signal to Earth to estimate the far-side gravitational field. The Chinese National Space Agency (CNSA) Chang’e 1 satellite entered lunar orbit on 5 November 2007 12 days after launch. The primary science objectives are to obtain 3D stereo images of the lunar surface, determine the distribution of elements on the surface and estimate their abundance, survey the thickness of lunar soil, and evaluate helium-3 resources, and explore the environment between the Moon and Earth.

4. ISRO’s Chandrayaan-1 is scheduled for launch in 2008 and will map the lunar surface using visible high resolution (5m) imager, hyperspectral imager, laser ranging, X-ray fluorescence spectrometer, infra-red spectrometer, and an imaging radar. NASA’s Lunar Reconnaissance Orbiter (LRO) is also scheduled for a 2008 launch with the primary goal of finding landing sites suitable for in situ resource utilisation, including a search for water ice. LRO’s launcher will smash into a permanently shadowed part of the Moon’s surface and will be followed a few minutes later by the accompanying Lunar CRater Observation & Sensing Satellite (LCROSS) that will analyse the plume of debris before impacting the surface.

5. Meanwhile NASA is driving hard to create the technology to allow astronauts to return to the Moon by 2020. The vision for the ‘Constellation’ programme is defined thus by NASA: “Astronauts will set up a lunar outpost — possibly near a south pole site called Shackleton Crater — where they’ll conduct scientific research, as well as test technologies and techniques for possible exploration of Mars and other destinations.”

6. What role if any should the UK play in this near-global burst of renewed interest in the Moon as a destination for space probes?

2.0 UK Background

7. The UK science community has a strong interest in planetary science and has played an important role in many European and international missions, such as Cassini-Huygens, Mars Express/Beagle 2 and SMART-1. Similarly, the UK space industry has made significant contributions to the design, development, construction and operation of many of the planetary missions, including the descent and landing subsystem and the onboard software for the Huygens probe to Titan, and the overall design and construction of Beagle 2.

8. Early in 2007 a ‘Space Exploration Working Group’ (SEWG) made up of experts from government, industry and academia was set up by Britain’s space agency BNSC and the UK Space Board. SEWG was tasked with reviewing the current global plans for space exploration and assessing what opportunities and benefits exist for UK participation, providing advice to the UK government on areas where the UK should focus if it wishes to engage in space exploration. In its report published on 17 September 2007 SEWG presented its findings against the four major themes of science, technology, knowledge transfer, commerce and society. Annex A describes in more detail these and other objectives of returning to the Moon.

9. On the subject of the Moon, SEWG recommended that the UK “initiate a targeted UK robotic lunar programme based on the use of low-cost satellites, rovers and resulting operational services, ideally in collaboration with other partners while keeping control of some key technologies.”

10. The SEWG also proposed a set of initiatives concerning wider solar system robotic and human exploration, public education and scientific investments. It concluded that “the proposed programme represents a broader ambition than the current science-driven exploration of space and so additional funds will be needed to provide the necessary activities in education, science, technology and knowledge exchange.” Finally, it asserted that “this will generate new scientific knowledge, increase excitement for science and technology in the young to help build the workforce of the future, and provide a grand challenge to invigorate the UK economy.”

3.0 UK Initiatives (further details in Annex B)

11. Various UK companies and institutes have provided hardware, software and services to SMART-1 and to the forthcoming Indian Chandrayaan-1 lunar mission.

12. Surrey Satellite Technology Limited (SSTL) and the Surrey Space Centre recently carried out a pre-phase-A study of a UK-led small-scale lunar mission funded by the Science & Technology Facilities Council. Two mission proposals resulted from the work — MoonLITE comprising a small orbiter and four un-braked penetrators with at least one targeted at the farside, and MoonRaker involving a single propulsive soft-lander targeted on a near-side landing site.

13. In other UK initiatives LogicaCMG is working with drilling companies in the UK and the USA to make recommendations on the potential for deep lunar drilling under telerobotic control from Earth. Meanwhile Astrium UK is participating in studies of ESAS’s MoonTwins concept for a combined orbiter and lander. Both LogicaCMG and Astrium UK are also participating in ESAS’s Aurora architecture studies, with LogicaCMG analysing information issues for in-orbit and on-surface operations, while Astrium UK is studying the communications and navigation architectures required for surface and orbital operations. Astrium is also a partner with the Open University in a proposal to NASA to re-fly the Beagle 2 science package to the Moon.

4.0 Options for the UK

14. Options for UK participation in lunar exploration range from a totally national mission, through bilateral missions for example with the USA, participation in ESA missions, and even participation in manned exploration of the Moon by joining the US Constellation programme or any other similar programme that emerges, e.g. a Chinese or Russian one. Each of these options is now discussed.

15. UK participation in any national, bilateral or international robotic lunar missions should make use of the experience and technology gained from other space missions, much of which is directly applicable to lunar missions. This is advantageous from an industrial point of view, but more importantly allows the development focus to remain on the core mission objectives, such as lunar science or technology demonstration.

16. The positive response of the British public to the Beagle 2 mission was facilitated by it being clearly a UK project. One of the weaknesses of bilateral missions with NASA is that the public will tend to see the project as a NASA mission with some UK involvement, unless the UK role is unambiguously that of leader. A similar perception problem can arise in British participation in ESA missions unless the UK involvement is as discrete and important as Beagle 2 was in ESA’s Mars Express project. If a UK lunar and solar system exploration programme is to be sustainable, public support on the scale of that evidenced by Beagle 2 will be required. Hence the UK should plan its activities so that it takes a lead role in visible and critical elements of whichever missions it participates in.

17. UK industry has a strong capability in building spacecraft, both at the small scale and larger interplanetary missions. The heritage and experience gained during the development of Beagle 2 has been continued with the ExoMars rover development, much of which could be applied to lunar landing missions. Given the limited resources likely to be available in the UK, affordability is an important consideration. Particularly in the case of national and bilateral missions, the UK expertise in the field of low-cost small satellite technology may provide a good basis upon which missions such as MoonLITE and MoonRaker could be developed.
18. The development of systems for exploration of the lunar surface could be used as a driver for advanced robotics, including mechanisms, software and miniaturisation. As an example of this, the oil exploration industry has already expressed interest in seeing what technology is developed to undertake deep drilling on the Moon’s surface.

19. The enormous public interest generated by the Beagle 2 mission to Mars suggests that lunar exploration could trigger a similar public reaction. The opportunities offered by the nearly universal access to the World Wide Web could be exploited. For example, a video feed from a rover traversing the Moon’s surface could be made available to the public, with annotation and/or voice-over to identify features of interest. If the rover has both wide-area and telescopic cameras, images from both could be selected by the viewer — similar to the options TV viewers are offered during Wimbledon tennis and Formula 1 racing. Real-time imagery from an orbiter could also be made available, annotated with information about the contents of the pictures. However, the leader of the Beagle 2 project, Prof Colin Pillinger, has pointed out that the human element in the project was an important reason for Beagle 2 capturing the public imagination. It is not clear how a robotic lunar mission without the charismatic involvement of someone like Professor Pillinger could repeat the Beagle 2 impact on the public.

20. Note also that the UK academic community has a great deal of expertise in building space instrumentation, both for orbiting spacecraft and also for landers.

21. The Agreement between NASA and BNSC signed in April 2007 calls for discussions on “collaboration involving lunar science and exploration.” This Agreement creates an opportunity for a sequence of missions to the Moon involving UK scientists and industry, allowing scientific objectives to be addressed in a systematic way. The first mission could build on existing payload capabilities, while later missions in the series could address more challenging objectives, such as surface exploration. The design of the first mission could take into account the objectives of later missions, undertaking investigations and developments that would facilitate the later missions. There is no indication yet that this agreement would extend to British astronauts being offered the opportunity to travel to the Moon, although it seems not to have been ruled out.

22. NASA’s Constellation programme is designed to allow international partners to play a role, albeit outside the NASA-only core programme. In conversations with RAEs Space Group Committee members on 13 December 2007, NASA Administrator Dr Mike Griffin confirmed NASAs wish to involve the UK as one such partner. He explained that the architecture is designed to allow partners to provide part or all of non-core functions such as communications, navigation, extracting oxygen from lunar regolith and power generation on the lunar surface on a ‘plug and play’ basis. Dr Griffin emphasised the importance of such additional facilities and services in enabling the USA to extend future lunar missions beyond the sortie concept of the Apollo era.

23. Options for collaboration should as far as possible aim to be supplementary to UK capabilities — and not compromise visible UK lead of a discrete and major mission element (see §16). For example, any British lunar initiative needs to find a launcher, and one attractive arrangement would be for the collaborator to provide the launcher rather than the UK having to purchase it.

24. The US initiative to return a human to the Moon seems likely to trigger human spaceflight initiatives in Europe and other parts of the world. There is little doubt that human spaceflight is of great interest to the public, politicians and media in the UK. However, the price tag of previous European and US programmes (most recently linked to the International Space Station, ISS) has been high, and many commentators consider that the UK did well to avoid a commitment to the ISS. There are concerns that the US Constellation programme to return to the Moon by 2020 risks incurring the budget hikes and schedule slippages that ISS has experienced. However, the framework for international participation in Constellation is not yet finalised, and it may prove feasible to negotiate a more bounded arrangement than that of ISS. The modular form of add-on services and facilities foreseen by NASA (see §22) may enable the UK to play a role in Constellation without the dependencies suffered by partners in the ISS.

25. Another piece of encouraging news is that a number of non-traditional developments are showing signs of providing affordable human spaceflight within the next decade. One example is the American SpaceX owned by Elon Musk, whose Falcon series of rockets is aimed at providing supplies and ferrying astronauts to the ISS, as well as launching commercial satellites such as the UK’s Hylas telecommunications satellite. Another technology strand is the SpaceShipTwo rocket-powered sub-orbital vehicle being developed by Britain’s Virgin Galactic based on the innovative designs of the US Scaled Composites company. The hope is that if SpaceShipTwo is a commercial success, funds will become available to develop the technology so as to provide a full orbital capability. Indigenous UK technology developments are also progressing, although none has quite reached the maturity of the SpaceX or Virgin Galactic examples. NASA’s decision to stop funding ISS operations after 2015 will trigger new thinking on human spaceflight in the ISS Partners (Russia, Canada, Japan and ESA), which will lead to options for the UK to consider.

26. The UK should therefore await the outcome of these interesting new developments before making long term commitments to developing human spaceflight facilities or technologies. Preparatory activities could be initiated to analyse the emerging options — in Europe, the USA, Russia, China and at home. It will probably be timely to take stock of the options in about 2012 or 2013.

27. A shorter term involvement in NASA’s Constellation programme on the basis of robotic technology, could offer British citizens the chance to become astronauts with the Moon as the potential destination. As explained by Dr Griffin, one straightforward arrangement would be for a UK astronaut to be chosen in the next round of ESA astronaut selection which starts on 19 May. Clearly the details of this opportunity need to be assessed before committing funds, but human spaceflight does seem achievable without the need for the budget normally associated with such activities. Other opportunities for human spaceflight can also be considered on a case-by-case basis, taking into account the cost effectiveness of the scientific and technical objectives.

5.0 Conclusions & Recommendations for Action

Conclusions

C1. There are exciting new opportunities for scientific investigation of the Moon.

C2. Despite great advances in our understanding of the Moon made possible by the American Apollo and Soviet Luna missions, many questions remain unanswered, for example concerning the Moon’s origin, and the history of the solar system as recorded in the lunar regolith.

C3. Collaboration is essential from a UK perspective if only to obtain a launcher.

C4. UK industry and scientists have shown expertise and ingenuity in previous planetary missions including the successful Huygens mission to Titan and the ill-fated Beagle 2 mission to Mars.

C5. Exploration of the Moon has the potential to drive technology advances.

C6. Lunar exploration is also a useful testing ground for exploration of Mars and other solar system bodies.

C7. In the longer term, the Moon provides an excellent platform from which to observe the universe and perhaps the Earth.
C8. New human spaceflight missions triggered by NASA’s withdrawal from the ISS in 2015 are likely to be proposed in Europe and beyond, and may offer interesting opportunities for UK participation. In about 2012-13, these should be weighed up against opportunities in emerging innovative programmes, such as Virgin Galactic.

C9. Robotic exploration of the Moon may catch the attention of Britain’s youth and the general public in a way similar to that achieved by Beagle 2. However, human spaceflight has much more intrinsic public appeal than robotic missions can ever hope to achieve.

C10. Lunar exploration can capture the interest of the British public if the UK is perceived as the leader of a major element of the programme.

C11. Robotic mission in NASA’s Constellation programme may provide low-cost flight opportunities for UK astronauts, perhaps via the ESA astronaut corps.

C12. UK involvement in a human Moon mission would probably generate great public interest and inspiration but long-term commitments should await the negotiation of the detailed partnership agreements.

C13. There are a variety of ways in which UK can participate in lunar missions over the coming decade, so the prudent course is to plan a programme of missions and developments designed to facilitate participation in collaborative missions as they emerge.

Recommendations

R1. Decision on UK participation in lunar exploration should take account of scientific, innovation and inspirational objectives.

R2. The UK should retain leadership of a discrete and critical element of any collaborative mission.

R3. It is timely for the UK to engage in dialogue with potential partners in a robotic lunar mission, especially partners that can provide a launcher capability, such as ESA, Russia, the USA, China and India.

R4. The UK should define a programme of robotic missions and related developments rather than a single project at a time in order to be ready to take advantage of opportunities as they emerge.

R5. Although science from the Moon is a longer term activity than science of the Moon, it is timely to begin the development of relevant precursor technologies.

R6. The UK should vigorously explore the potential for partnership in NASA’s Constellation programme, based on robotic facilities and services in conjunction with associated astronaut flight opportunities.

R7. The opportunities for the UK to participate in human spaceflight technology developments should be kept under review, especially as concerns the new launcher options now beginning to emerge. Long term commitments to such developments should be avoided until the results of these options become available, hopefully in about five years time.

ANNEX A. Objectives of Returning to the Moon

A1. Participation of the UK in the return to the Moon offers the opportunity to achieve a number of scientific, technological, commercial and inspirational objectives.

Science of the Moon

A2. The Moon is a unique environment in which to study the early evolution of our solar system. Many of the processes that have transformed the surface and interior of the other terrestrial bodies (Venus, Earth and Mars), such as plate tectonics, planet-wide volcanism, wind and rain are not present on the Moon, resulting in a near-pristine record of the geological processes that were key to the formation of our planet.

A3. A key objective of returning to the Moon is therefore to increase our scientific understanding of it and as a consequence the evolution of the Earth.

A4. The SEWG report (Ref. 4, p 17) gives the main goals of lunar exploration as:

■ determine the origin of the Moon and how that affected the development of the early life on Earth; and

■ investigate the record of solar and collision histories embedded within the lunar regolith (soil layer, probably several metres deep).

Science from the Moon

A5. The rotational period of the Moon is synchronous with its orbit period, resulting in one side always facing the Earth. This feature offers the opportunity to use the Moon as a platform for a variety of other types of science, such as astrophysics or Earth observation. The SEWG report (p 71) notes that “the Moon is a vantage point from which to undertake new and challenging observations.”

ANNEX B. Objectives of Returning to the Moon

A11. A clear objective of the US space programme is the return of humans to the lunar surface, leading eventually to a future manned mission to Mars. Moon-based astronauts will provide opportunities for investigating lunar geology, as well as for deploying other scientific experiments. However, one of the consequences of the US commitment to a manned lunar programme is their withdrawal of funding for the International Space Station (ISS) beyond 2015. The ISS partner organisations (ESA, Canada, Japan and Russia) therefore must fund ISS operations without the $3bn or more per annum the US currently pays towards it, or be left without a target for human spaceflight activities. This situation may trigger new and varied human spaceflight programmes by those agencies and countries.
B1. In 2006, the UK Science & Technology Facilities Council (formerly known as PPARC) funded Surrey Satellite Technology Limited (SSTL) and the Surrey Space Centre to carry out a pre-phase-A study of a UK-led small-scale lunar mission. A fundamental driver was that any UK-led mission must be affordable, while satisfying key science objectives not previously addressed and offering the opportunity for educational outreach and stimulation of 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 first system design was performed and design cost drivers in terms of science performance and required technology were identified. In the end, two mission proposals were established, namely MoonLITE and MoonRaker(5).

B2. MoonLITE (Moon Lightweight Interior and Telecom Experiment) consisted of a small orbiter and a rover that used a rake to probe a pre-selected penetration site. The scientific goal is to map a network of seismology and heat flow experiments to investigate the seismic environment and deep structure of the Moon. The four penetrators would be distributed over the surface, with at least one in the far side and one in the same area as the Apollo 17 landing site. One penetrator, if possible, would be targeted at the South Pole-Aitken Basin on the lunar far side and equipped with a sensor to detect water or other volatiles. The orbiter payload would include a navigation signal and communications demonstration package and support equipment for the penetrators.

B3. The launch would be a direct injection into trans-lunar orbit by India’s PSLV. The orbiter carries a MMH/NTO bipropellant motor with a 400-500N main thruster. This system would perform the manoeuvres to place MoonLITE into a 100km altitude circular polar lunar orbit. The total ΔV required for the mission is 1.217kms⁻¹. MoonLITE would be a three-axis stabilised satellite and carry a full complement of SSTL micro-satellite avionics. Communications to and from Earth for TT&C would be performed in S-band and the orbiter would carry a Ku-band receiver for a high-rate surface communications demonstration. The nominal ground station for the mission is the 12m antenna at Rutherford Appleton Laboratory located at Chilton in Oxfordshire. Launch is targeted for the timeframe 2010-2011.

B4. Each penetrator would weigh 36kg and contain a de-orbit propulsion system capable of slowing it down to 300ms⁻¹ at impact. The penetrators would create a passive seismological network capable of monitoring the deep interior over a one year mission lifetime. The penetrators would all carry instruments for measuring heat flow. Data would be relayed from the penetrators to the orbiter via the coverage of 30kbits per day. The UK’s interests in penetrator technologies are gathered into a national consortium comprising research institutes such as UCL/MSSL, Birkbeck College, the OU, QinetiQ, Imperial College and University of Surrey, plus a number of industrial players. The consortium has been investigating key design elements of lunar penetrators including structure, science instruments, power, communications and data handling. The concept has been proposed to ESA within the Cosmic Vision Call for Ideas.(13)

B5. MoonRaker would involve a single propulsive softlander targeted on a near-side landing site with direct communications to Earth. The mission has a primary goal of attempting in situ dating of the young basalt at northern Oceanus Procellarum. MoonRaker would establish a low-cost European lander capability for robotic exploration of the Moon. The mission could be implemented as a bilateral or multilateral approach. A ready-made pathfinder for drilling in the Moon, not only do we learn more about the Moon itself, and by association, our own Earth, but we also pave the way for more ambitious and exotic missions to the planets.(12) The LogicaCMG initiative for the next generation of lunar and terrestrial drilling will see advanced visualisation, simulation and remote control techniques being shared between the space engineering and terrestrial oil & gas drilling communities. Drilling companies in the UK and the USA are working with LogicaCMG to make recommendations on the best way forward for deep lunar drilling(6).

B6. More generally LogicaCMG is a member of two European consortia defining Europe’s future exploration architecture — one team looking at the in-orbit systems, the other at those on the surface. LogicaCMG is defining the information management aspects of both architectures.(7) Astrium UK is a member of two other consortia analysing these same architectures, and is studying the communications and navigation architectures required for surface and orbital operations.

References
11. The Global Exploration Strategy Framework, ASI (Italy), BNSC (United Kingdom), CNES (France), CNSA (China), CSA (Canada), CSIRO (Australia), DLR (Germany), ESA (European Space Agency), ISRO (India), AXA (Italy), KARI (Korea), JSAT (Japan), KARI (Korea), NASA (United States of America), NSAI (Ukraine), Roscosmos (Russia), May 2007 (available at http://www.bnsce.gov.uk/assets/celestrium/media_centre/Global%20Expo
13. LogicaCMG website: http://www.logicagcm.gm.com/350233169/LogicaCMG+strikes+oil+with+new+vision+for+Moon+drilling/400008183
14. For further details see: http://www.mssl.ucl.ac.uk/planetary/ The Newsletter by J. PHILPOT, ‘The payo...