SSC07-I-6

Smallsats to the Moon: Providing the 'Picks and Shovels for the 21st century's greatest exploration endeavour'

Adam M. Baker, Andy Phipps, Philip Davies, Xavier Alabart[1], Martin Sweeting
Surrey Satellite Technology Limited (SSTL)
Tycho House, 20 Stephenson Road, Surrey Research Park, Guildford, GU2 7YE, United Kingdom; +44 (0) 1483 803803,
a.baker@sstl.co.uk, x.alabart@sstl.co.uk, a.phipps@sstl.co.uk, p.davies@sstl.co.uk, m.sweeting@sstl.co.uk

1 *Currently on a placement from the International Space University, Masters in Space Management course, Strasbourg, France.*

ABSTRACT

Small spacecraft have an enviable history of changing the economics of space. Space development and exploration has historically been costly, and going beyond Earth orbit even more so. However the cost-performance balance of small spacecraft has increased to the point where new commercial business cases using space infrastructure can be enabled. This paper outlines SSTL's approach to low cost missions, and its validity to exploration, in particular the Moon. The political environment for supporting space missions, particularly exploration in the United Kingdom is covered, including study activities building the case for a national exploration programme and their fit to strategic UK space goals. Results from a recent study funded by the UK government to explore feasibility of low cost lunar mission concepts are presented. The MoonLITE lunar orbiter and penetrator mission and Moonraker soft lander are summarised. Commercial prospects for future lunar missions, driven by a desire to increase public value for money are discussed, outlining some of the services small spacecraft could provide to support the lunar explorers of the 21st century. The authors propose that small satellites will act cost-effectively as the 'picks and shovels', or essential tools of the explorers. History suggests that such service provision can demonstrate a return on investment.

INTRODUCTION

2006 and 2007 have seen growing British interest in the international exploration Lunar programme. The US driven 'Vision' with major efforts by India, Japan, Russia and China, who are beginning with robots but have mostly committed to a manned programme suggest a steadily increasing level of activity on the Moon in the next decade.

SSTL and the Surrey Space Centre have been investigating lunar missions since 1996, and have conducted numerous in-house, European Space Agency (ESA) funded and most recently nationally funded studies for the UK PPARC. However the prospect of small, affordable spacecraft regularly visiting the Moon and providing useful scientific returns is still only a prospect. Although SMART-1, and Clementine demonstrated that lunar exploration could be conducted for costs between $80 and $200M, neither opened the door to regular low cost missions. Most lunar exploration to date, notably of the lunar surface has run into the billion dollar range, with Apollo the best known example. NASA's Lunar Reconnaissance Orbiter due for launch in 2009 has also shown that lessons on cost-effective exploration have not yet been learnt, with a programme cost to completion estimated to exceed $0.75B. ESA has no lunar missions in its manifest at present.

In contrast, SSTL whose missions start at below $10M, has developed hardware which is already flying into interplanetary space: This includes the European Space Agency Rosetta lander momentum wheel, which will stabilise the lander module during its attempt to soft land on the comet. SSTL has also recently completed its OBC695 computer as the payload processor for the Chandrayaan-1 mini-RF radar payload, designed to search for lunar polar volatiles and launching in 2008. SSTL has also celebrated its first mission year beyond LEO with the successful GIOVE-A mission, demonstrating key technologies and securing frequencies for the future Galileo global navigation constellation. This hardware experience, in combination with the series of studies of lunar missions carried out since 1996, gives the authors the firm belief that SSTL's approach to cost effective Earth orbit microsatellites could have great benefit to future space exploration.

SSTL, SMALLSATS AND EXPLORATION

SSTL's goals are both simple and ambitious. This small British company with less than 300 employees has delivered 26 mission to Low Earth Orbit (LEO). It built the first Galileo spacecraft, currently operating in Medium Earth Orbit (MEO) and is building a backup copy for ESA. A small geostationary orbit spacecraft is being developed following initial British national Space Centre (BNSC) and now ESA ARTES funding. The logical next step, and one of SSTL's four cornerstone business goals for the next 5 years is to build an interplanetary (lunar) orbiter by 2010. Success on an orbiter, itself with deployable surface probes, would be followed by soft landing, the first time for any wholly British built vehicle on another planet. Soft landing is planned to lead to deployment of other surface hardware, such as robotic rovers and subsurface drills, which are a British industrial strength (see Figure). In this regard, the Moon represents only series of steps on the road to the greatest prize in solar system exploration: The search for life on Mars.

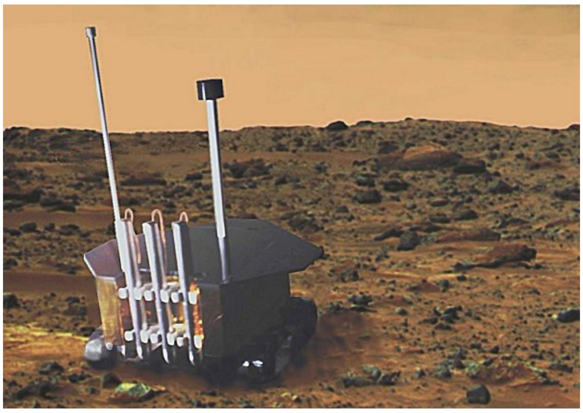

Figure 1: British Robotic expertise opening up the Red Planet at low cost: the Endurance micro rover (Surrey Space Centre / Ashley Green)

SSTL is developing its own internal lunar roadmap with the following missions:

1. Detailed feasibility studies (Phase A) in 2007.
2. Development of lunar penetrator / impactor payload alongside pathfinder orbiter mission for launch in 2010.
3. Delivery of an early service communications relay / navigation test signal orbiter in 2012.
4. Soft lander with complex science payload in 2013/2014.
5. Lunar sample return demonstration after 2015.

The above missions, intended to be carried out as part of a major UK (industry, academia and government) exploration effort is intended to unfold alongside the 21st century's greatest exploration endeavour: human exploration and settlement beyond the Cradle of the Earth. In delivering the low cost missions capabilities and scientific knowledge which are planned, SSTL aims to demonstrate that the cost of (human) space exploration can be dramatically reduced by judicious application of cost-effective robotic missions. Robotic missions are not designed to supplant human exploration, but to complement them, offering:

- Technology risk reduction through demonstration and pathfinder missions.
- Conducting environmental surveys, and monitoring planetary surface and in-space conditions prior to astronaut arrival.
- Provision of tertiary services, i.e. not transportation / in-situ mobility, and life support but communications, navigation, power augmentation and scientific instrument delivery and support. In the longer term, construction, sample retrieval / analysis and search / rescue functions are envisaged.

SSTL firmly believes that low cost, rapid missions must be used to underpin larger exploration initiatives to ensure the latter offer a balance of risk and cost acceptable to the taxpayer. Carrying out the tasks suggested above with low cost small missions is both feasible and necessary. Historical lessons from Apollo, preceded by Surveyor, Gemini and many Russian lunar missions 'paving the way' to the first manned landings support this argument.

Nevertheless, why does SSTL believe that it can change the economics of space exploration?

Firstly, SSTL has pioneered affordable, yet reliable and applications focused space missions. Many have followed and frequently challenged SSTL – yet when Aviation Week and Space Technology ran an article in December 2003 entitled 'smallsats grow up', an SSTL microsatellite was on the front cover.

Secondly, SSTL claims growing heritage at subsystem level beyond LEO as well as many years of study experience in challenging Earth Orbit and interplanetary missions. SSTL has also been operating a complete mission (GIOVE-A) for over 18 months in the challenging MEO environment, and has delivered performance with its LEO microsatellites for a cost an order of magnitude less than many traditional aerospace systems. Indeed, SSTL's TOPSAT spacecraft is often referred to as TACSAT-0 by the Responsive Space movement.

Finally, external evidence has indicated that the cost of traditional space missions, notably for the US government, is now so high that a new paradigm is needed. Couple this with excitement from capable, small and cost effective missions such as Clementine, New Horizons and Smart-1, and the growing capability of even smaller EO spacecraft, and the case for smallsats supporting exploration initiatives seems clear.

NASA has clearly stated in its presentations on Exploration strategy that small satellites are an affordable way to deliver robotic mission infrastructure [1]. Whether this implies that human infrastructure for the Moon is seen as unaffordable is a point for debate, although the booming space tourism industry is also looking beyond LEO and may enable not just NASA astronauts to reach the moon within a few decades.

UK CONTEXT FOR EXPLORATION

Surprisingly for a country with one of the world's largest economies, and a highly developed users of high-technology, there is government 'anchor customer' in the UK, such as the space agencies in many other similar countries who purchase regular missions and / or services. SSTL, formed in 1985 largely had to develop its own market for cost-effective, rapid delivery space missions following its first two successful microsatellite missions in 1981 and 1984. UoSAT-1 and -2 demonstrated both a market for store and forward communications and Earth imaging at low cost, and the viability of secondary launches to orbit small satellites at low cost.

Recognising the growing value of small spacecraft, the BNSC funded a US$30M programme between 2000-2005 to demonstrate small satellite technologies in collaboration (MOSAIC). MOSAIC gave SSTL the opportunity to design its capable DMC (Disaster Monitoring Constellation) and TOPSAT platforms (shown below), and begin development of a small GEO platform, GMP. TOPSAT, costing <$25M and its co-passenger Beijing-1 (shown below) also built by SSTL demonstrated the real utility of small spacecraft for Earth imaging, in competition with much larger and more costly traditional space systems [2].

Figure 2: TOPSAT high resolution, 100kg class microsatellite

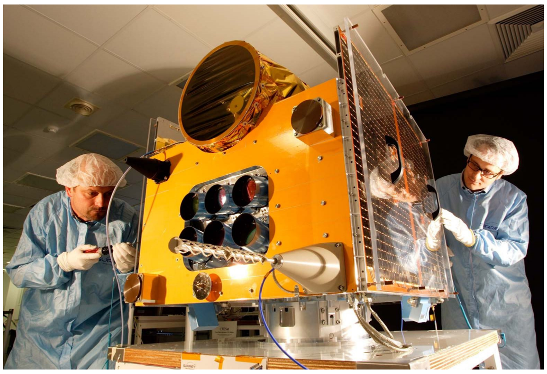

Figure 3: Beijing-1, high resolution and wide swath 160kg class microsatellite

Small space systems are also being built by SSTL and other companies to customers requiring a space element to complete a business case. Examples include RapidEye, a German business serving the agricultural insurance industry, and an upgraded DMC with improved camera resolution, image quality and downlink rate is being built by SSTL for the Spanish customer Deimos Space, serving a growing market for low cost Earth Observation images in Spain and Portugal.

In parallel to the growing Earth orbit small satellite market, there is growing British interest in international Lunar exploration efforts. The US driven 'Vision for Space Exploration' with major efforts by India, Japan, Russia and China, who are beginning with robots but are weighing the benefits of manned programmes implies steadily increasing levels of activity on the Moon in the next decade. The table below lists some of likely lunar missions over the next decade:

Mission	Origin	Launch date	Objectives
Selene	Japan	2007	Remote sensing (chemistry + image mapping), water detection, gravimetry, radiation, topography.
Chang'e-1	China	2008	Image mapping, topography, chemistry, water detection.
Chandra-yaan-1	India	2008	As per Selene, excluding gravimetry.
LRO	USA	2008	Image mapping, radiation, topographic mapping, water detection.
LCROSS	USA	2008	Impactor: search for water ice at Lunar south pole
Lunar-A	*Japan*	*2010*	*Penetrators for geophysics* (unofficially cancelled).
LPRP	USA	2010	In-situ water detection.
LunaGlob	Russia	2013	Inc. penetrators + soft lander, water detection & seismometry.
Chang'e-2	China	2013	Lunar rover
Selene-2	Japan	2013	Lander + rover + impactor
MSR precursor	ESA	2015+	Aurora programme Technology and operations demonstration for Mars Sample Return

Table 1: International Lunar missions in the next decade

The challenge for SSTL is to help meet the growing UK socio-political need for a high profile affordable UK national mission to another planet, while meeting the UK's policy requirements for government funded space activities. UK policy requirements are explained in the UK space strategy 2003-2006 [3] are:

1. Enhancing the UK's standing in astronomy, planetary and environmental sciences.

2. Stimulating increased productivity by promoting the use of space in government, science and commerce.

3. Developing innovative space technologies and systems, to deliver sustainable improvement in the quality of life.

Viewed another way, space activities not designed to enhance scientific knowledge and generate world class publishable results must 'pay their own way' or at least demonstrate value to the economy. Bearing this challenge in mind, the UK Space Exploration Working Group (SEWG) was formed in November 2006 by the Director–General of the BNSC and the Chairman of the UK Space Board, with the following objectives:

- Review current global plans for space exploration;

- Assess whether or not a rationale exists for UK participation, and;

- Provide advice to BNSC as to which areas the UK should focus on if it wishes to engage in such activities.

The working group was split into task groups:

1. The first group is reviewing the scientific rationale for space exploration (robotic and human), focused on key destinations (Moon, Mars, asteroids and others to be agreed).

2. The second group is assessing the technological and knowledge transfer goals for space exploration (robotic and human).

3. A third group is evaluating the wider societal benefits from space exploration, including at least educational, outreach, political.

4. A fourth and final group is tasked with summarising the short and long term commercial opportunities (manufacturing and services) arising from global space exploration.

Reports from all four groups will be synthesised into a consistent format to make conclusions and recommendations to the UK Space Board and Space Advisory Council prior to the next International Space Exploration Conference to be held in Bremen, Germany, in October 2007. Furthermore, the results will be used to support the Case for a UK (National) Space exploration programme being made to UK government as part of the Comprehensive Spending Review for the next 5 years of UK government spending. Thus, at the time of writing of this paper, the UK is preparing to make a significant decision which could lead to an expansion of civil space activities, budgets and public involvement.

The authors of this paper are all involved in drafting the Commercial section of the UK SEWG report, this is expected to have a major influence on the final UK spending review decision and whether the lunar missions described in the next section go ahead.

UK GOALS FOR EXPLORATION

The United Kingdom is both a nation with a long heritage for exploration, and one which possesses a strong service driven economy. Mindful of these issues and of its own limited space budget, and currently lacking a strong exploration mission focus for its industry, space-inspired youth, and world class science community, the PPARC agency commissioned SSTL and partners to take a fresh look at the feasibility and value of a UK lead lunar mission by 2010.

A UK national mission would aim to serve UK goals and complement those of the European Space Agency and its Aurora exploration programme. Aurora has run since 2000, although its first mission 'ExoMars' [4] is not expected to launch until at least 2013. UK goals for an interplanetary mission were derived from the BNSC strategy described earlier, and in brief are :

1. A desire to stimulate young people to study science & technology (educational outreach),
2. Support development of innovative robotic technology, to enable UK industry a leading role in international science & exploration missions,
3. Provision to UK scientists of good opportunities for research, particularly in the field of lunar geology, enabling world class science.

These objectives could all be met through a UK lead high profile planetary surface mission, building on many compact, high performance instruments developed at by UK universities and industry [5].

Between May and November 2006, SSTL, the University of Surrey Space Centre and a small working group of UK lunar scientists were funded by the UK Particle Physics and Astronomy Research Council (PPARC) to study the feasibility of a low cost lunar mission addressing the key UK objectives. A further objective was to optimise the mission deliverables for a mission cost an order of magnitude less than traditional interplanetary missions, supporting PPARC funding requests to the UK government. The successful GIOVE-A platform delivered to ESA in under 30 months for a 28M€ (US$37M) contract value was used as a reference example. The consortium working arrangement is shown below:

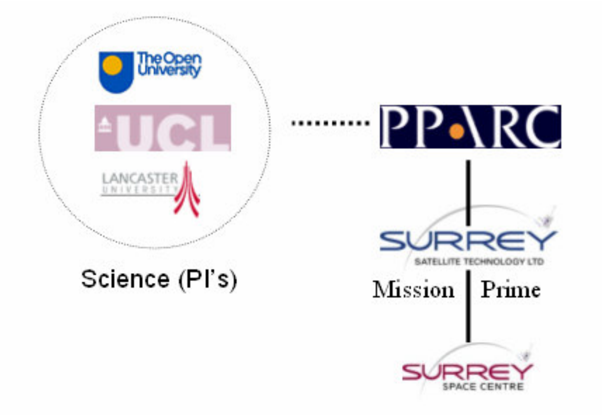

Figure 4: UK lunar study consortium

SSTL viewed this study as a major opportunity to support UK government interest in rapid, low cost space science missions. These would complement larger, more complex ESA science and exploration missions (the UK contributes more than half of its ~£190M annual space spending to ESA, and is keen to achieve maximum value for money with the best synergy between national efforts and funding spent through ESA).

SSTL believes that there is a great danger for the current space exploration programmes, particularly ESA's Aurora and NASA's Vision for Space Exploration. If these grand, long term efforts become too costly and too slow to deliver results which capture public imagination, the public will not support their funding and the politicians will consequently cancel the programmes. Thus, as a community, the space industry must offer a rapidly paced programme which delivers results in short timeframes at affordable prices. Smallsats could be, in fact should be the way to do this.

LOW COST MISSION CONCEPTS

Two low cost rapid mission concepts have been developed for PPARC, and have been summarised in detail at recent lunar mission symposia [6,7]:

MoonLITE (Lightweight InTerior Experiment) orbiter,

The MoonLITE mission concept comprises a small orbiter and four penetrators, shown in Figure 5. 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 a year (a few lunar orbits for heat flow, and much less for volatiles). Provision for penetrator descent imagery would be desirable for both science context and outreach purposes.

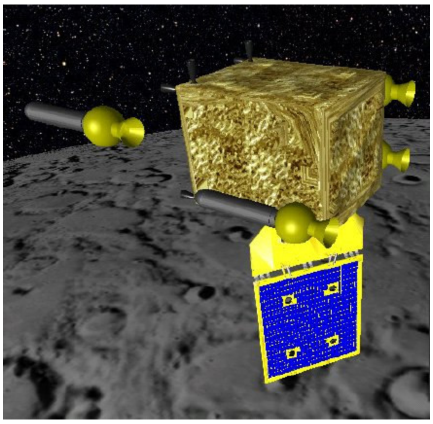

Figure 5: MoonLITE mission

MoonLITE has been designed to fit a tightly constrained budget, less than £75M for the complete mission including penetrator development, launch and operations and could be ready for launch by late 2010. MoonLITE is also seen as a pathfinder mission capable of demonstrating service to be delivered for a future lunar constellation of small satellites. This constellation would meet communications relay, navigation positioning signal and space weather monitoring requirements, and could potentially deliver instruments to or above the lunar surface. A mass budget for MoonLITE, is given below:

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 & comms. / nav. 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**

Table 2: MoonLITE mass budget (kg)

PSLV was selected for MoonLITE as the lowest cost launcher with heritage capable of delivering a small mission onto an interplanetary trajectory. Selection of PSLV as the launcher, and the penetrator plus comms / nav. Payload drove the mission design from both ends of the trade-tree. Coupled with the cost constraint a first iteration optimization was produced, equivalent to a pre-Phase A study.

Moonraker

The Moonraker propulsive soft-lander, shown below, aims to provide a low-cost European lander capability for extensive robotic exploration of the lunar surface in preparation for subsequent human expeditions and sample return. The first Moonraker mission is targeted to the lunar near side, allowing 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 terrestrial surfaces throughout the whole Solar System.

The envisaged in situ method involves a K-Ar dating technique being investigated at the University of Leicester. 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 and discussion is ongoing among UK instrument and science experts 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.

Figure 6: Moonraker lander

Moonraker landers would take advantage of the latest developments in robotics and autonomy, incorporating greater intelligence than ExoMars through, for example vision-based guidance for the terminal phase to allow precise autonomous landing autonomously on the ejecta blanket of a suitable crater. This capability 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 program, and several UK companies and laboratories are already involved.

Other mission concepts were studied in addition to MoonLITE and Moonraker but due to baseline technology uncertainties could not be costed with sufficient accuracy to merit further technical analysis. Sample return was discarded after an initial top down estimate found too great a design uncertainty to make it suitable as a low cost mission option. Lunar sample return was further addressed in a separate study by the University of Surrey Space Centre [8]. Present scientific community opinion seems to suggest that for the budget required, a Near Earth Object sample return would offer better science. The table below summarises the mission level trades made for the different concepts studied:

Lunar Mission	Launcher (mass budget)	Benefit	Initial cost estimate
Orbiter	Shared Proton to GEO (400kg)	Low: little useful orbital science	$100M
Orbiter + up to 4 unbraked penetrators	PSLV (800kg to TLI)	Medium: Geophysics – heat flow, seismology	>$10M
Soft lander, direct entry	PSLV (800kg to TLI)	Medium-High: Geochemistry	Approaching $200M, considerable uncertainty
Soft lander & comms relay	Soyuz-Fregat (1600kg to TLI)	High: Geochemistry – no restriction on landing site	At least $200M
Sample return	Either Soyuz-Fregat (1600kg to TLI), or Ariane V Cyclade (500kg in GTO)	Moderate-High: Geochemistry with higher fidelity than in-situ measurements	>$500M, ~100% uncertainty using Soyuz-Fregat approach

Table 3: Affordable lunar missions studied by SSTL

COMMERCIAL PROSPECTS FOR THE MOON

The concept of 'commercialising space' is not new. However the space industry is often seen as a place to spend money, not to make money. Excepting a few service providers such as telecommunications relay and direct to home broadcast companies operating geostationary satellites, margins are low and profits are scarce for both infrastructure and many service providers. Given the many challenges of space exploration (technical risk being only one such challenge!), commercialisation might be seen as even less attractive than other areas currently being explored such as Earth observation and navigation / positioning related services.

A typical space hardware company, in doing business is tries and answer the question 'how can we as a hardware manufacturer increase the likelihood and number of hardware sales to the exploration initiative?' In contrast the likely near term customer for lunar and interplanetary platforms, typically a national government or space agency, takes the view 'how can we enable private sector money injection to improve public sector value for money?' Reconciling these two views is the key to enabling small spacecraft missions for delivery of lunar services.

From a business development viewpoint, the problem is that commercial opportunities that exist in space exploration are potentially vast, but they are not generally well enough defined to sustain a business case which could attract significant or underpinning private sector finance. Although commerce will also eventually see the opportunities to exploit mineral and other resources in space, and will exploit the benefits of investment of advanced scientific exploration, this is many decades ahead and requiring a robust exploration programme with early results to provide evidence to support business cases. The current situation is that opportunities for purely public sector financing of exploration are limited, except for delivery of science (noting the UK space strategy key objectives [3], i.e. science, stimulating productivity and improving the quality of life). Put another way, it seems clear that the governmental resources available to the endeavour are insufficient to propel mankind towards its destiny in space at a satisfactory rate of progress. Our conclusion is that the firepower of private industry needs to be harnessed, used as a tool to achieve long run objectives.

Recommended approach for stimulating exploration:

1. Bring commerce into the strategy from the outset, allowing companies to build credibility, expertise and a track record of success that will encourage investment into space exploration in the future.

2. Business plans based on the provision of services which are protectable and sustainable are preferred by capital markets, against the irregular cash flows

that result from simple hardware sales. Business opportunities offering smooth growth based on evidence of expertise are the key to obtaining finance.

3. Consortia of companies should therefore be encouraged to develop, targeting a service provider model in support of exploration strategies. This requires resources over a period of 15 years or more to be committed to the purchase of services (rather than "hardware", or "missions"), which will catalyse capital markets to take the risk(s) that the consortia can deliver against their promises. 'Promises' are the explicit services, explored next. Note also that in a service provider model, consortia may be willing to provide services on a less than 100% cost recovery basis if in return, rights over future exploitation are made available.

4. The market for the service provider model must be broadened as far as possible. China, India, the USA and other nations / agencies have clear plans to send manned missions to the Moon and Mars. So, the opportunity exists for the service provider to generate significant economies of scale and scope by selling its basic services to all of these nations. Thus the primary risk takers (government agencies, e.g. NASA, ESA, JAXA) can focus their resources on funding their basic targets, leaving tertiary services to the capital markets and consortia they support. Again, the tertiary services are discussed next.

5. Further, the UK's extensive experience in project and Public/Private Partnership financing should be brought to bear. Skynet 5 [9], providing secure communications to the UK military, via a public / private partnership lead by the Paradigm consortium is a potential model. Public / Private Partnership financing would be combined with UK expertise in space insurance and low cost space instrumentation and platform technology. The latter through the pioneering efforts of SSTL have demonstrated that small spacecraft now offer sufficient cost-benefit to offset their costs from the sale of (Earth Observation) data, which one external and one internal SSTL customer are currently exploiting, through the Spain-DMC and Uk-DMC2 spacecraft due for launch in 2008.

6. Finally, energizing a political drive to persuade other nations to outsource work to British consortia could produce incredible leverage.

The authors believe that application of the above model offers every possibility that the UK government could harness private resources to produce the most comprehensive and powerful space exploration capability in the World.

Potential services (delivered by a low cost lunar mission)

Services, their metrics and the precise details of the business model are still being researched at SSTL and developed within the UK Space Exploration Working Group. The most likely services which could be delivered using small satellite infrastructure in the next 5-10 years are:

- Delivery of scientific instrumentation to lunar orbit and retrieval of associated research data.
- Communications relay: return of high added value but non time critical data. Backup to existing systems delivering with safety-of-life data, such as spacecraft (&life support) telemetry, and astronaut voice communications.
- Monitoring and Early warning of space weather events, e.g. solar coronal mass ejections.

Potential services more suited to the 10+ year timeframe are:

- Provision of power to lunar facilities, construction services on the lunar surface and transportation services to CISlunar space.
- Offering navigation services, including augmentation of navigation positioning signals using surface transponders. Several orbiters could offer accurate and frequent positional updates.
- Delivery of scientific instrumentation to the lunar surface and retrieval of associated research data. Ultimately this could extend to sample or payload return from the surface to Earth orbit or Earth surface facilities.

Looking in particular at the quantifiable market for communications relay, in the next 10 years at least 10 missions will be visiting the moon, many of which will land or impact the surface. A simple, first order revenue model assumes a communications transponder on each mission capable of transferring data to a UK lead communications relay spacecraft. A suitable charging structure, for initial access and then per unit of data transferred could provide a revenue stream for the mission provider, ultimately feeding back to UK government as taxes and industrial employment. The following strawman assumes a typical medium rate transmitter, antenna and pointing mechanism:

- Each Transmit/Receive unit requires 20-60kg mass (including propellant) to reach lunar orbit.
- At current launch rates of >$25000/kg (India's PSLV) to Earth escape, delivering the mass only of a 'bare bones' relay transceiver to lunar orbit would cost $0.5-1.5M.
- The cost of including such a transceiver system on each planned mission would be, say, $1.5M from current industry suppliers.

Assuming ten missions paid to use this system as backup or primary data and TTC relay (hence saving mass), the potential revenue could be $20-30M, an attractive offset to the public outlay to develop such a mission, and potentially attractive to private finance backers. Charging per unit of data transmitted and providing data relay for more challenging surface landing missions would further increase the value of a shared telecommunications relay. Further elaboration of lunar data relay architectures, potential customer requirements and mechanisms to establish the best revenue stream is needed. Considerable work has been done by NASA, for example [10], although requirements need to be set in the international context.

UK ACTIVITIES AT PRESENT

A number of activities are expected to take place over the next few months in the UK:

- The UK Space Exploration Working Group will complete its report and report to the UK Space Board and Space Advisory Council, who will then make representations to government on the case for a UK national exploration programme.
- A UK Penetrator Consortium will plan in detail the development, costing and teaming for the MoonLITE lunar penetrator payload.
- A UK industry team including SSTL will be formed to develop and ultimately deliver the MoonLITE mission.
- SSTL will study Mars Sample Return precursor missions, including lunar orbiters for ESA under a European consortium.

SUMMARY: THE CASE FOR (LUNAR COMMERCIAL) SPACE USING SMALLSATS.

SSTL believes that there is a great danger for the current space exploration programmes. If they become too costly and too slow to deliver results which capture public imagination, the public will not lobby for or support funding, and the programmes risk cancellation by politicians. Thus, as a community, the space industry must offer a rapidly paced programme which delivers results in short timeframes at affordable prices. Smallsats are clearly an effective means of supporting and exciting, cost-effective space exploration programme.

SSTL as an industrial company with shareholders seeking a return on their investment is trying to answer the question 'how can we develop business selling lunar and exploration mission hardware and related services'. In contrast, the UK government, which is a likely near term customer for SSTL's lunar and interplanetary platforms, is asking the question 'how can we enable private sector finance injection to improve public sector value for money'? A multi-step approach culminating in a public-private partnership, already demonstrated in the UK for delivery of space based service to the UK military, is offered for consideration by the authors.

Small spacecraft, which SSTL has delivered 27 of to LEO and MEO, are proposed as the most cost-effective means of delivering tertiary services to support large government exploration initiatives. These initiatives will likely place significant infrastructure into CISlunar space in the next 2 decades. Required services will range from communications data relay and provision of navigation positioning signals in the near term, to provision of power, delivery (and retrieval) of surface scientific instruments and site services such as construction in the longer term.

In a manner analogous to the Gold Rush of the mid-1800s on the US West Coast, the most profitable operations were not those involved with gold digging, but sale of essential tools: 'picks and shovels' to the miners. Small satellites are the 'picks and shovels' of the 21st century's greatest exploration endeavour.

REFERENCES

1. Dale, S.; '(NASA's) Exploration Strategy & Architecture,' speech to the 2nd Exploration Conference, Houston, December 2006. Available at http://www.nasa.gov/pdf/163896main_LAT_GES_1204.pdf

2. A. da Silva Curiel, L. Gomes, D. Purl, D. Hodgson, W. Sun, M. Sweeting, 'First year in orbit – results from the Beijing-1 operational high resolution small satellite,' presented at the 6th IAA Symposium on small satellites for Earth Observation, Berlin, Germany, April 23-26, 2007. pp. 8.

3. 'UK Space Strategy 2003-2006 and beyond, ' British National Space Centre, 2003. Available at http://www.bnsc.gov.uk/assets/channels/about/5818%20BNSC%20Brochure.pdf, last update unknown, accessed 10 June 2007.

4. 'ExoMars,' ESA Aurora exploration programme, http://www.esa.int/SPECIALS/Aurora/SEM1NVZKQAD_0.html , last update 19 January 2007, accessed 10 June 2007.

5. D. Pullan, M.R. Sims, I.P. Wright, C.T. Pillinger & R. Trautner, 'Beagle 2: the Exobiological Lander of Mars Express,' In: Mars Express: the scientific payload. Ed. Andrew Wilson, scientific coordination: Agustin Chicarro. ESA SP-1240, Noordwijk, Netherlands: ESA Publications Division, 2004, p. 165-204. Available from http://sci.esa.int/science-e/www/object/doc.cfm?fobjectid=35195

6. A. J. Ball, I. A. Crawford, L. Wilson, D. Parker, A. Phipps, J. Clemmet, M. Taylor, P. Davies, A. da Silva Curiel, Y. Gao, A. Baker, M. Sweeting, 'Low-cost lunar mission options,' poster presentation at the International Space University 'Why the Moon' symposium; February 2007.

7. Y. Gao, A. Phipps, M. Taylor, J. Clemmet, D. Parker, I. A. Crawford, A. J. Ball, L. Wilson, A. da Silva Curiel, P. Davies, M. Sweeting, A. Baker, 'UK Lunar Science Missions: MoonLITE & Moonraker,' paper presented at the DGLR International Symposium "To Moon and beyond", Bremen, Germany, 14-16 March 2007, pp. 9.

8. A. M. Baker, A. Phipps, M. Sweeting, A. Ellery, Y. Gao, 'Challenges and options for an affordable small lunar sample-return mission,' IAC-06-IAF-B1.2.06, presented at the 57th International Astronautical Congress, Valencia, Spain, October 2006; pp. 9.

9. P. de Selding, 'Skynet 5A launch has Paradigm, Astrium breathing easier,' Space News, march 19, 2007. p. 6.

10. G. K. Noreen, R. J. Cesarone, L. J. Deutsch, C. D. Edwards, J A. Soloff, T. Ely, B. M. Cook, D. D. Morabito, H. Hemmati, S. Piazzolla, R. Hastrup, D. S. Abraham, M. K. Sue, F. Manshadi, 'Integrated Network Architecture for Sustained Human and Robotic Exploration,' IEEEAC paper #1378, Aerospace Conference 2005 IEEE, 5-12 March 2005. pp. 20.