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AN UPDATE ON MOONLITE

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ABSTRACT

MoonLITE is a proposed, UK led lunar science mission involving 4 scientific penetrators that will make in situ measurements at widely separated locations on the Moon. MoonLITE will create the first global lunar network with nodes near and far-side, and in permanently shaded crater(s). With such a network MoonLITE will be able to determine much about the interior of the Moon, including characterisation of its core. Penetrator(s) at the poles will seek and characterise frozen volatiles, possibly of cometary origin and of great importance both to human exploration and to astrobiology. MoonLITE penetrators will reach the Moon at ~300 m/s and so must be able to stand the forces associated with this impact. As part of a programme aimed to establish reliable penetrator technologies the first full-scale impact trials have been conducted and are described here.

1 INTRODUCTION

MoonLITE is a proposed, UK-led lunar science mission comprising 4 scientific penetrators that will make in-situ measurements at widely separated locations on the Moon [1]. The Mass of each penetrator will be around 13Kg. The MoonLITE penetrators are planned to impact the lunar regolith at ~300m/s, embedding themselves ~ 2-5m under the surface. Then unlike 'impactors', a suite of scientific instruments designed to withstand the impact will perform a range of key investigations.

While there has yet been no successful planetary deployment of such high speed penetrators, there is no reason to believe that they are inherently less reliable than soft landers. The only high speed penetrators to be delivered to a planetary surface were those of Deep Space-2 (DS-2) which formed part of the ill fated Mars Polar Lander mission for which both soft lander and penetrators were lost [2,3]. The Russian Mars'96 mission [4] included penetrators but failed to leave Earth orbit, and the Japanese Lunar-A programme [5,6] was cancelled after many delays before it could be launched. Of course all of these programmes included numerous successful ground trials and impact technology has a long history and is very mature, albeit not within the space sector.

The UK penetrator development programme combines extensive expertise in space instrumentation with the defence sector's capability to design, model and prove high velocity instrumented shells. The success of the recent full scale, impact trial reported below, demonstrates the effectiveness of this combination, and forms a cornerstone for the future program.

2 MOONLITE

In 2006 the UK Science and Technology Facilities Council (STFC) commissioned a study of low cost Lunar missions by Surrey Satellite Technologies Ltd. A Penetrator-based mission was included in the study and identified MoonLITE as the leading contender. Soon after this BNSC and NASA formed a joint working group working on lunar cooperation which described MoonLITE as 'inspirational' and recommended it for a full phase-A study. In July 2008 an international peer review strongly endorsed the MoonLITE mission concept and also recommendation that it proceed to a phase-A study.

The MoonLITE concept consists of a single spacecraft which delivers 4 high speed penetrators to globally separated sites around the lunar surface from a polar lunar orbit [7]. The spacecraft will then provide communications between the sub-surface penetrators and Earth during their 1 year nominal mission lifetime. After this period, when the penetrators are no longer operational, the orbiter would continue to operate as a communications and navigation experiment.

A Descent Module (DM) comprising a penetrator and a Penetrator Delivery System (PDS) (Fig.1) will be ejected from the host orbiter. The PDS provides de-orbit thrust and attitude control manoeuvres to slow down its penetrator for near normal incident angle impact at 300m/s into the lunar surface. Each DM is essentially a complete miniature spacecraft.

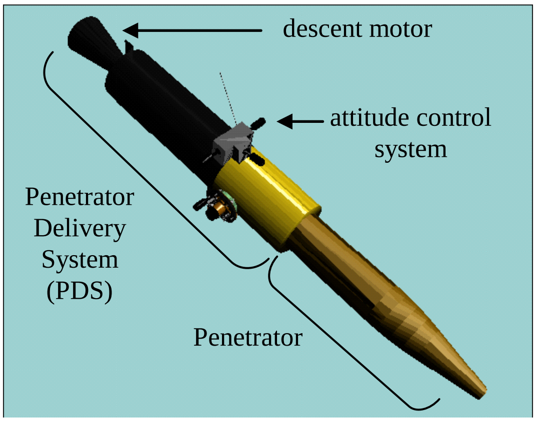


Figure 1: Preliminary Concept Of Penetrator Descent Module (DM) [7]

The PDS will also control the attack angle (angle between the penetrator long axis and velocity vector) to within a nominal 8 degrees to prevent excessive lateral gee forces. Just before impact the PDS will be separated from the penetrator to avoid contamination of the impact site. During delivery it is planned that a descent camera will take images of the impact site for both scientific context and public outreach.

The impact velocity is designed to achieve penetration to a depth of around 2 to 5 metres, an ideal emplacement for sensitive seismometer investigations, and also a thermally stable environment suitable for heat flow measurements.

The impact sites are nominally selected to include :-

- One near the existing Apollo sites to provide continuity
- One on the far side for which there has not yet been a landing.
- One near each of the poles in the permanently shadowed craters to allow investigation of the orbitally indicated existence of water ice, and for other possible volatiles. There have also not yet been landings at either of these sites.

These sites are globally distributed to create a seismic network much more widely distributed than the previous Apollo instruments which were confined to a small, nearside triangle. They will also allow sampling of much more diverse lunar geological terrains.

2.1 MoonLITE Objectives

The scientific objectives of MoonLITE include [8] :-

- To further our understanding of the origin, differentiation, internal structure and early geological evolution of the Moon via seismic, heat flow, and possibly magnetic investigations.
- To obtain a better understanding of the origin and flux of volatiles in the Earth-Moon system, via chemical sensors at the permanently shadowed polar sites. This could include volatile chemistry relevant to possible astrobiological seeding of planets.
- To determine the variation of lunar mineralogy and chemistry at diverse geophysical regions not previously sampled.
- To obtain 'ground truth' geochemical data to complement orbital remote-sensing observations.

MoonLITE also has the potential for wider benefits that include :

- Determination of the extent and usefulness to future human Lunar missions of in-situ resources such as water and volatiles at the polar sites; effectiveness of lunar regolith for radiation shielding (a radiation monitor will be studied as a possible payload element); and regional characterisation of large but possibly damaging surface quakes to lunar human habitation and instrumented scientific stations.

- To act as a forerunner to inform the planned International Lunar Geophysical Network (ILN).
- The MoonLITE mission will provide a show case for UK innovative technology particularly in the area of low cost satellites.
- Penetrator technologies have application to a wide variety of solar system bodies including the moons of the major planets, Mars and Asteroids. Penetrator options (led by the UK penetrator consortium) are being studied for the ESA Cosmic Vision programme (LAPLACE/EJSM, TandEM/TSSM and Marco Polo). The success of our first full scale impact trial programme has led to significant levels of interest in ESA
- The UK penetrator development programme has already attracted a great deal of media and public interest, and public engagement will stimulate young people's interest and involvement in science and technology.

2.2 Penetrator & Payload

The penetrator itself will contain power, data handling, communication subsystems and a scientific payload.

Fig.2 shows the preliminary design which incorporates a tail flare to assist straighter flight within the regolith.

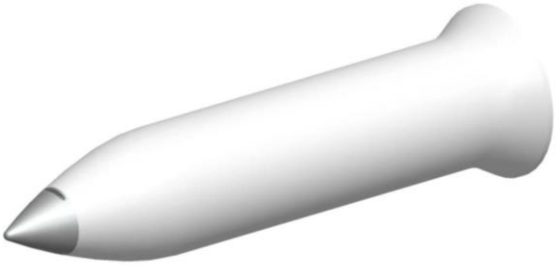


Figure 2: Preliminary MoonLITE Penetrator Design (~13Kg, ~0.5m long)

Table 1 shows the currently identified core and additional potential payload elements for MoonLITE, together with their space heritage

Example of payload components are the micro-seismometer suspension and elements from the mass spectrometers shown in Figs 3 and 4 respectively.

Payload (nominally ~2Kg)	**Objective**	**Heritage** (examples)
Core		
Micro-seismometers	Lunar internal structure and quake activity	ExoMars (IC)
Heat flow package	Lunar internal structure (radio-isotopic material abundance). Subsurface temperature, conductivity, permittivity.	Thermal & Heat flow Lunar-A (OU), Permittivity (IWF)
Chemistry package	Water, volatiles and refactory chemical characterisation	Rosetta mass spect., GAP (OU), Beagle-2 XRS (LU), DS-2 drill (JPL)
Accelerometer	Regolith structural composition and layering (depth under regolith)	Lunar-A, DS-2. (Defence heritage QinetiQ)
Descent camera	Scientific context of impact site and public outreach.	ExoMars (MSSL)
Potential		
Radiation monitor	Shielding properties of regolith	(QinetiQ Space)
Magnetometer	Remanent magnetisation. Lunar internal structure.	Many space missions (IC)
Mineralogy camera	Global variation of sub-surface regolith mineralogy	New development. Simple but robust.

Key: IC = Imperial Colleg; JPL= Jet Propulsion Laboratory, US; LU=Leicester University; IWF= Space Research Institute, Graz, Austria; OU = Open University.

Table 1: MoonLITE Penetrator Potential Payload

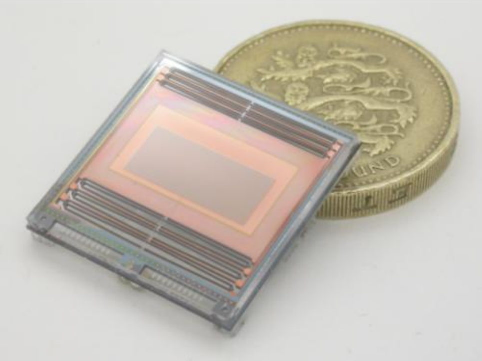


Figure 3: Micro-seismometer (Imperial College)

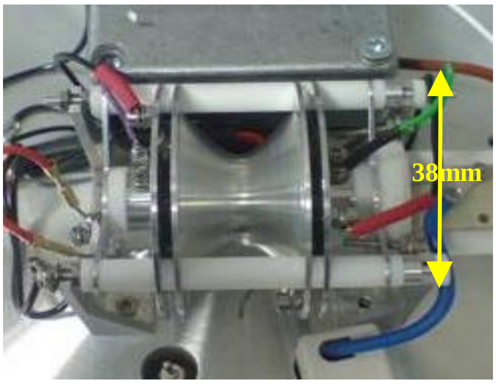


Figure 4: Prototype Ion Trap Mass Spectrometer (Open University)

3 IMPACT TRIAL

3.1 Objectives & Trial Parameters

Though many of the penetrator subsystems and instruments have prior space heritage, demonstration of the ability to survive impact is required. A first step in this process was implementation of a full scale trial at the expected impact velocity of MoonLITE. This took place during May 19-21 2008 at the Pendine test track in Wales with the firing of 3 penetrators on consecutive days.

The selected trial parameters were :-

- 3 identical penetrator shells: Aluminium; ~13Kg; 0.56m long, 12cm external main body diameter.
- Contents of penetrators were not identical: Housed within inner bay units, for ease of development, integration and test.
- Impact: 300m/s at normal incidence.
- Target: dry sand (first order regolith simulant)

Though only 9 months from conception to trial, a fairly comprehensive payload was developed, to meet the following substantial set of objectives :-

1. Demonstrate survivability of penetrator shell, accelerometers and power system.
2. Assess impact on penetrator subsystems and instruments.
3. Determine internal acceleration environment at different positions within penetrator.
4. Extend predictive modelling to new impact and penetrator materials.
5. Assess alternative packing methods.
6. Assess electrical interconnect philosophy.

The prime objective was to demonstrate survival of the QinetiQ designed penetrator shell, accelerometers and power system, and to use the accelerometer data to characterize the impact gee forces along the primary direction of deceleration. This was considered a feasible objective because of the extensive QinetiQ heritage with instrumented shells, allied with their predictive modelling capability to identify problems with the design before committing a design for manufacture and the trial itself.

Secondary objectives were to obtain information on the effects of the impact gee forces on embedded payload instrument and subsystem hardware for which no prior modelling would be performed, though QinetiQ heritage on packing and configuration of the hardware would be employed. Consequently, no survivability requirements were made on these elements. The objective here was more to identify potential weaknesses which could be addressed in future trials. MSSL provided additional accelerometers in the rear of the penetrator which could determine the magnitude of the gee forces in lateral directions.

3.2 Modelling and Simulation

Prior to performing the trial, a major part of the project was to model the penetrator design and simulate the impact, to identify any high stress locations that might lead to failure, and to predict the penetration depth. A variety of independent techniques of varying sophistication were used.

The results of this modelling predicted that an Aluminium penetrator of the proposed design would survive normal impact into sand at 300m/s, though impact at an angle would result in striations to the nose and some damage to the rear due to ‘tail slap’ on impact.

However, the penetration process would depend heavily on the exact nature of the sand, making prediction of the penetration depth uncertain, resulting in estimates ranging from around 2.5 to 3.5m. Here, the results from the trial would provide valuable feedback into modelling the target material, especially useful for enhancing future predictive accuracy for impact into potentially more representative lunar regolith simulants.

3.3 Trial Configuration

Each day a penetrator was mounted onto a sled (Fig.5) which in turn was mounted on a horizontal railed track (Fig.6).

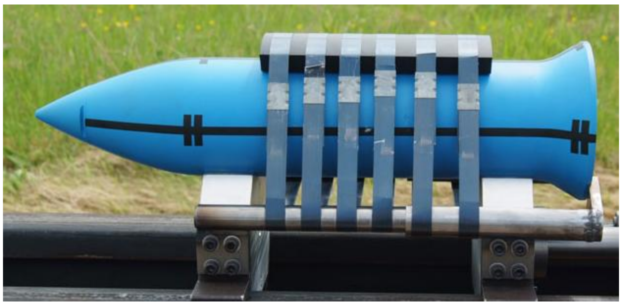


Figure 5: Penetrator mounted on its sled, on the Pendine test track.

Figure 6: Penetrator mounted in front of rocket-sled with target in the distance

A separate rocket sled accelerated the penetrator (~40 gee) along the track to more than 300m/s for ~0.9sec. The sleds then travelled unpowered to the end of the track where a bar cut the penetrator restraining bands allowing the penetrator to fly freely the last ~13m to the target. It initially impacted through a thin polythene sheet window (Fig.7) designed to contain the target material and protect it from the weather, before passing into a 2m wide, 2m high and 7m deep volume of compacted sand.

Figure7: Impact target showing entrance aperture. In the foreground at the bottom is a tube which catches the sleds.

The penetrators were also painted uniformly blue to help capture the inflight images with high speed cameras, and black lengthwise fiducial markings on the sides to indicate any degree of rotation from firing to final resting position.

3.4 Penetrators Configuration

Four aluminium penetrator shells were constructed (one spare), each containing a set of inner bays (Fig. 8).

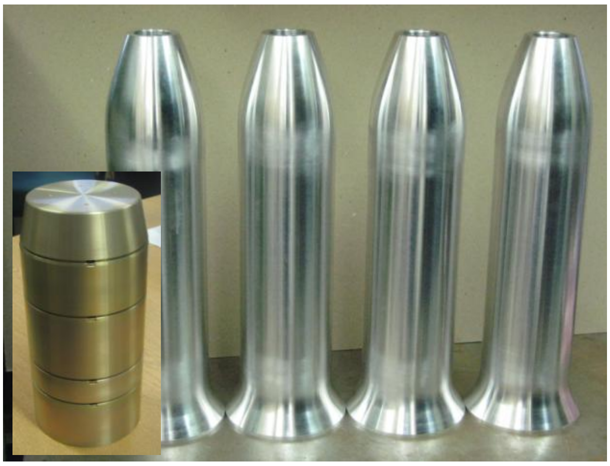


Figure 8: Impact trial penetrator shells and one inner payload bay stack

The internal structure of the penetrator is shown in Fig.9, and the detailed contents of each inner bay for each penetrator is described in Table 2.

In addition 3 types of packing were also investigated (a) potting compound, (b) glass microspheres, and (c) none (voids) as indicated in the table.

	Penetrator-1	Penetrator-2	Penetrator-3
Nose	Aluminium	Aluminium	Steel
Front end	Accelerometer, Thermometer, Power Data logger	Accelerometer, Thermometer, Power, Data logger	Accelerometer, Thermometer,. Power, Data logger
Compartment-A	Magnetometers	Batteries, Radiation sensor	Batteries, Radiation sensor
Compartment-B	Drill axis (void)	Micro-seismometer suspensions	Micro-seismometer suspensions
Compartment-C	dummy	Mass spectrometer Components (glass microspheres)	Mass spectrometer Components (void)
Compartment-D/E (Rear)	Power, Accelerometers, Onboard processing, Interconnection harness	Power, Accelerometers, Onboard processing, Interconnection harness	Power, Accelerometers, Onboard processing, Interconnection harness

(A potting compound has been used as packing material unless otherwise indicated in brackets.)

Table 2: Penetrators Configuration

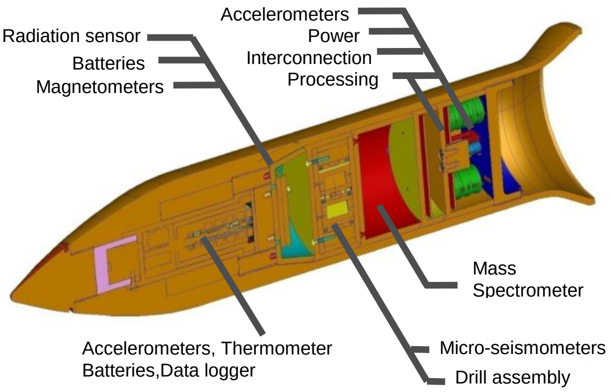


Figure 9: Penetrator internal bay structure and contents locations.

3.5 Trial Results

Following each firing, the first task was to locate the penetrator in the target and record its position and orientation. A summary of these firing and post impact location details are provided in Table 3 which shows a remarkable consistency between each of the 3 firings.

All impact velocities were slightly greater than nominal. Also, the pitch (attack) angles were significantly higher than planned, very near the maximum value specified for flight and just exceeding it for the first impact. Such an attack angle will be expected to cause severe lateral gee forces. These impacts, therefore, represented a worst case for the penetrator survival. Though in the second and third firings various measures were instigated to attempt to correct the nose-up impact these proved unsuccessful. Notably, for the third firing in order to move the centre of gravity forward, a steel nose was used rather than and aluminium one.

Though not planned, the first penetrator encountered additional forces when first the metal cutter bar (designed to separate the binding straps from the rocket sled) intersected with the rear penetrator mounting metal bar, and finally at the end of the impact with a glancing blow off a steel girder (in place to support a roof for the target, designed to prevent the penetrator escaping). Also, in the second firing, the penetrator again impacted a steel beam at a similar position, but this time more fully, displacing it by several inches. The resulting damage to these penetrator noses is shown in Fig.10.

The observed penetration depths of around 4m exceeded the maximum predicted depth of 3.5m, a discrepancy that is currently being resolved.

In addition, examination of the penetrator in the target revealed, in each firing, negligible rotation, and no significant removal of the blue paint on the top or most of the side surfaces, though all the paint from the nose had been ablated away. Lifting the penetrator from the target revealed extensive removal of the paint and erosion of the underside of the penetrator consistent with the nose-up impact, and also significant deformation of the rear flare. For the third firing, the steel nose caused a significantly changed depth of ablation, with less ablation of the nose itself but more of the aluminium just behind the nose. These effects are shown in Fig.10.

The intact recovery of the penetrator from each of these worst case trial scenarios is in itself a major success.

	Impact velocity [1] (m/s)	Pitch Angle [2] (°)	Yaw [3] (°)	Mass (Kg)	Penetra-tion distance (m)	Post impact location in target/ Additional impact history	Penetrator Survival
Penetrator-1	311	+8.3°	+1.0	12.99	~3.9	Top surface/ Impacted steel cutter bar and girder	✓
Penetrator-2	310	+6.6°	+1.7	13.46	~3.9	Top surface/ Impacted steel girder	✓
Penetrator-3	309	+7.8°	+1.9	13.73	~3.8	10cm below top surface.	✓
Nominal	300	0	0	13.00			

Notes: (1) Impact velocity - average of coil and high speed camera data, (2) Pitch/attack angle (nose up) - at impact, (3)Yaw angle at impact.

Table 3: Trial Results Summary

(a) Penetrator-1 resting position in target, showing little rotation; extensive nose but no significant top surface body ablation

(b) Penetrator shell ablation of nose, underbelly, and tail flare distortion and behind steel nose of 3rd penetrator

(c) Penetrator-1 nose post impact

(d) penetrator-2 nose post impact

Figure 10. Post Impact Penetrator External Shell Damage.

Samples were taken of the target sand material at various positions from the target. Analysis of these gave an average density of 1.6 ± 0.3 Mg/m^3 and water content ranging from 3 to 5%. The sand was composed of generally polished and poorly sorted gains consisting primarily of quartz, fine-grained siltstone, concrete fragments, metamorphic rock fragments, anthracite coal, shells and minor quantities of accessory mineral phases. The most common grain size (~30%) was in the 250-106μ range, with less than 12% >2000 μ and <0.2% smaller than 100μ. This appears to be consistent with the sand origin from the bed of the Bristol Channel, though it is noted that the grain size is significantly larger than that expected in the Lunar regolith, which will be addressed in future trials.

An unexpected observation of dark material underneath the resting position of the penetrator in each firing, which tracked back along the entry trajectory was found to be consistent with that of the anthracite coal component in the sand. The mechanism is thought to result from the passage of the penetrator mobilising the water particles and breaking up the anthracite particles which were found to have coated the other component sand grains.

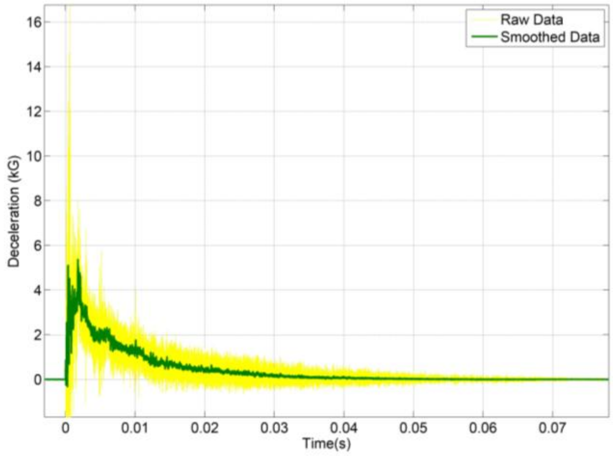
Following recovery of the penetrator from the target, access to the inner payload bays by unscrewing the plug at the rear of the penetrator as expected proved impossible, due to the nature of the deep aluminium screw threads and impact distortion. By lateral sawing through the penetrator rear section access to the rear MSSL bays was made, and subsequent lengthwise angle grinding then allowed removal of the inner bay stack. Examination of the internal penetrator space showed no distortion, such that it is still possible to insert and remove inner stack assemblies from the spare structure.

The results of examination of the payload components were as follows :-

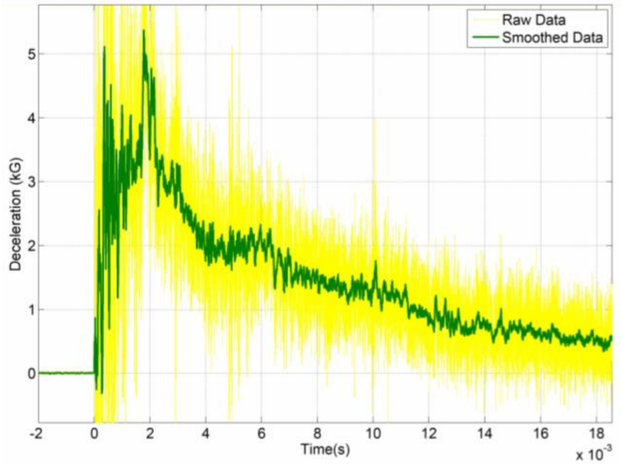
a) **Front End Accelerometer, Thermometer, Power, & Data Logger Bays**.

All this equipment functioned perfectly throughout the all 3 test firings and all the data was recovered post test. The data logger was initiated by the impact with the target and gave high time resolution accelerometer data throughout the main impact as shown in Fig.11 which shows the data from the 1st firing. This shows force peaks of ~16kgee in the direction along the long axis of the penetrator, with smoothed values of 5kgee. The high time resolution plot shows that the largest peak occurred after the initial impact which we believe is consistent with the impact of the penetrator belly just before the impact of the tail flare.

The thermometers showed a rise in temperature of a few degrees, possibly consistent with the short duration they were active during the impact process itself.



(a) QinetiQ Accelerometer Data



(b) High time resolution accelerometer data

Figure 11: QinetiQ Impact Accelerometer Data from 1st Penetrator Firing

b) **Rear End Accelerometers, Data Processing, Bay-Interconnection & Power Bays**

All this equipment functioned perfectly throughout all the tests, and remained functional. The only failure was premature activation of the data logging in the second test because of a set-up error not allowing sufficient time for the electronics to settle before activation. However, the equipment functioned perfectly and remained operational subsequently.

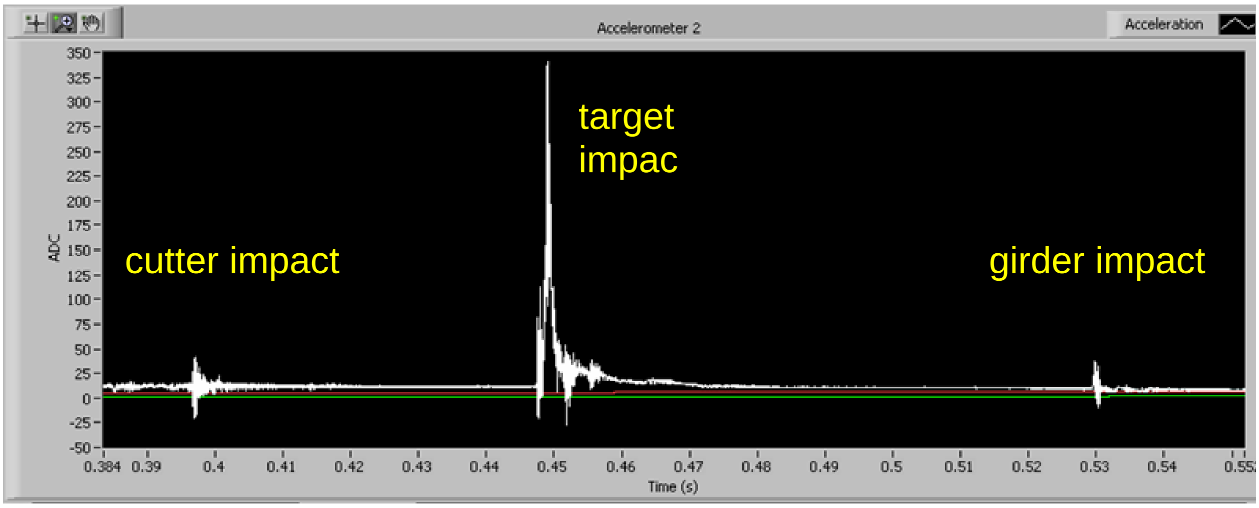


Figure 12: MSSL along axis accelerometer results (1st firing, ~11 kgee maximum)

The results show that the power system functioned perfectly, including the electrical harness, without any loss of power during impact. Both non volatile and volatile RAM contained the expected data which was successfully downloaded post test.

The along axis accelerometer data obtain from the first trial is shown in Figure 12. This also shows the initial impact of with the cutter bar before the penetrator sled left the track (~1 Kgee), and the final impact with the girder (~3Kgee). The forces in the lateral directions show a similar profile but with a much small maximum in the horizontal (yaw) direction of ~4kgee but ~17kgee in the vertical (pitch) axis. These results clearly show that the maximum forces were not experienced in the direction of travel, but laterally due to the nose-up impact angle.

c) Micro-Seismometer Bays

These contained micro-seismometer suspension units which are the most sensitive and delicate element of the micro-seismometers. In flight, only 3 suspension units are required, but for this investigative test 48 suspensions were flown, 24 in penetrator-2 and 24 in penetrator-3. These were arranged in different orientations, and had different impact protection methods, which ranged from nothing to full embedding in various sublimating materials.

Fig.13 shows one of the micro-seismometer bays as recovered post test impact, which shows no signs of external damage.

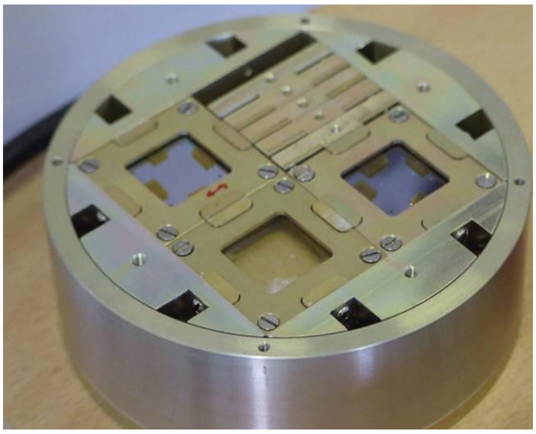


Figure 13: Recovered Micro-Seismometer bay Post Impact

Unprotected suspension units suffered damage as expected. Units where springs were fabricated of vary widths but without proof mass survived. This simulated the situation where the proof mass is clamped during impact.

Other units encapsulated the whole proof mass and spring suspension within a sublimating solid like PDB (Para dichloro benzene), Napthalene & Camphor. These solids sublimate at an accelerated rate when exposed to vacuum. Here, 11 out of 12 dies encapsulated in PDB survived without damage; 9 out of 12 dies encapsulated in Napthalene survived without damage. However, the Camphor solidification process was aggressive breaking the dies pre-trial, and was not used in the trials themselves.

d) Sample Acquisition Assembly Bay (drill component)

Fig.14 shows the drill bay which contains the drill axel mounted on a test mount**.** Post test analysis show some damage to the mounting assembly but not the drill axel. Since this is not a flight mount design this is not considered a serious. Moving parts were still mobile after impact.

e) **Mass Spectrometer Bays**
These contained the following mixture of Commercial Off The Shelf (COTS) components and mechanical model of in-house designed and manufactured ion trap mass spectrometer :-

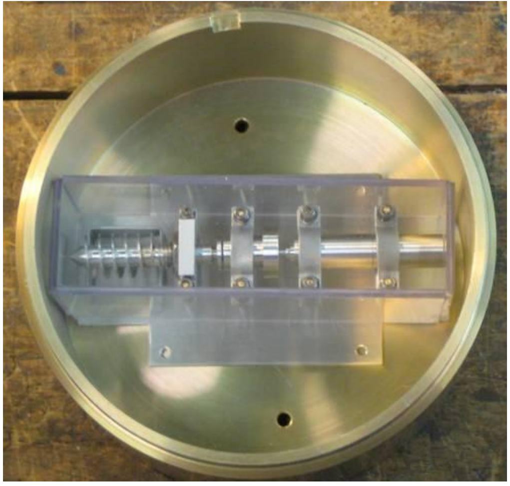


Figure 14: Sample Acquisition Drill Bay (Surrey Space Centre)

- Penetrator-2: This was fully instrumented & packed with solid glass microspheres. It contained a mass spectrometer unit, ion detector, ion source 6" tungsten filament, charge amplifier, electron multiplier, and pressure sensor.
- Penetrator-3: This was partially instrumented & unpacked. It contained a mass spectrometer unit, dummy ion detector, ion source with 3" tungsten filament, dummy charge amplifier, electron multiplier, and pressure sensor.

Post trial the unpacked bay contained damage to pressure sensor, 3" filament, and mounts to dummy charge amplifier and electron multiplier, and a mounting screw. However, the packed bay saw only damage to the pressure sensor, and extraction shield to the 6" filament. In both cases the mass spectrometer unit was undamaged.

f) **Magnetometer Bay**
Two orthogonal single axis ceramics and a dual axis plastic magnetometer sensor, both based on magnetoresistance, were mounted on circuit boards and encapsulated in the potting compound. These were not powered during firing found but survived without damage.

g) **Batteries and Radiation Monitor Bays**
Radiation monitor mounted on a circuit board and 2 lithium batteries occupied each bay in the 2nd and 3rd penetrator firings unpowered during the impact. All units survived, though ~50% capacity reduction was noticed in the batteries. Investigation into the cause of this continues.

In summary, all the trial objectives were either met or exceeded. Three worst case parameter firings produced consistent results with only significant failures of the MEMS pressure sensor, and battery capacity reduction. In both these cases, however, a number of alternatives exist. In particular, suitable batteries have already been penetrator qualified for both Lunar-A and DS-2, and several alternatives.

4 CURRENT STATUS AND FUTURE PLANS

Following the outcomes of both the JWG and International Peer Review, preparations have been underway for the mission phase-A study. This study will comprise three elements (i) the mission (including orbiter, launch and operations); (ii) the Penetrator Delivery System (PDS) including DM system issues, and (iii) the Penetrator itself. In parallel with the Phase-A a technology development programme is envisaged that will bring each subsystem/instrument up to Technical Readiness Level (TRL) 5 necessary for the project to proceed to Phase-B/C/D.

The expected timescale is to initiate this program by the end of this year. The Phase-A would consist of an initial 9 months period. Following a phase review another period of ~ 1 year is envisaged (delta Phase-A) while the technology programme completes, though it would also pick up items arising from the initial Phase-A study.

It is planned to have 2 more full scale impact trials during this period, where again pre-trial simulation modelling will be used to de-risk the main impact trials. In addition, small scale trials will also be used to address specific issues. Also during this period, potential interested international partners will be sought. A payload instrument announcement of opportunity will be issued before phase B. Launch is planned for 2014.

5 SUMMARY AND CONCLUSIONS

MoonLITE has made two important step forwards in recent months. The endorsement by an International Peer Review of its science objectives and the mission provides important scientific legitimacy. The very successful impact trials demonstrated, in a very real way, that the penetrator element of MoonLITE was likely to be technically feasible. Currently, we are advanced in the process of planning and seeking funding for a Phase-A study of the MoonLITE mission, and for the necessary parallel program to establish TRL 5 within

2 years for the impact survival of the penetrator instruments and subsystems.

The information gained from the first trial provides key information on the likely gee force environment to be encountered for both along axis and lateral directions and magnitude and high frequency components of forces. It also has provided survival likelihoods for significant instrument and subsystem components; and packing methods to ensure survival, and how to internally connect and harness the penetrator. The inner bay concept provides a workable and useful method to achieve a clean and simple Assembly Integration and Test (AIT) process with simple integration and swap out of units. The glass sphere packing method also shows promise in allowing easy post test examination of contained subsystems. Finally, it has confirmed the value of the modelling and simulation for survival, and provided important feedback into accuracy of simulating more complex geologic material.

Additionally, the success and timing of this programme is crucial to potential selection of penetrators for outer planet missions such as Europa, Ganymede, Enceladus and Titan.

Finally, the low mass of such penetrators, make them compliments to otherwise orbiter-only missions. The ability to provide measurements at globally spaced sites on planetary bodies either as a full (e.g. seismic) network, or as additional or replacement elements, is also an attractive benefit for hitch hiking such instruments.

6 REFERENCES

[1] Yang Gao, et. al., “Lunar science with affordable small spacecraft technologies: MoonLITE and Moonraker”, Planetary and Space Science, Vol. 56/3-4 pp 368-377.

[2] “Mars Polar Lander/Deep Space 2”, Press Kit, December 1999. NASA publication.

[3] “Mars Polar Lander”, http://mars.jpl.nasa.gov/msp98/index.html

[4] “Mars96, http://www.iki.rssi.ru/mars96/mars96hp.html

[5] Shiraishi, H., Tanaka, S., Fujimura, A., and Hayakawa, H., “The Present State of the Japanese Penetrator Mission: LUNAR-A”, 8th ILEWG Conference on Exploration and Utilization of the Moon. July, 2006.

[6] Lunar-A Mission, http://nssdc.gsfc.nasa.gov/database/MasterCatalog?sc=LUNAR-A.

[7] M. Taylor et. al., “MoonLITE – A Low Cost Lunar Scientific and Technology Demonstration Mission”, 59thIAC, 29th Sep-3Oct 2008, Glasgow

[8] Crawford, I.A. and Smith, A., "MoonLITE: A UK-Led Mission to the Moon", Astronomy and Geophysics, 49, 3.11-3.14, (2008) [http://zuserver2.star.ucl.ac.uk/~iac/AG_MoonLITE_article.pdf]