Landing Strut Energy Absorption Technologies and Reliability Investigation

Introduction

Lunar Mission One plans to send an unmanned lander to the south pole of the Moon in approximately ten years' time – specifically the Shackleton crater. The landing site will be within a pre-determined 100 m^2 area near the edge of the crater such that the lander will have sufficient exposure to sunlight for its solar panels. Once there, the lander will drill 20-100 metres deep into the surface to investigate rock samples and will also place a digital archive of life on Earth, alongside some DNA samples that will last for a billion years.

The placement instructed that research be done into a topic area surrounding a specific part of the mission or the spacecraft itself. The engineering and technologies associated seemed an important area of the mission to investigate, hence conferred is an analysis of potential technologies.

Abstract

One of the key risks in Lunar Mission One was identified to the landing, specifically with energy dissipation. Presented is an investigation into the landing strut energy absorption technologies that could be adopted on the Lunar Mission One lander in order to achieve a soft landing with as great a reliability as possible.

Methodology

The project required the creation of a literature review on a chosen topic relating to Lunar Mission One. Paul Bennett, the representative for Lunar Mission One, gave an initial presentation informing on the proposed mission's details including the orbital dynamics, landing procedure, the digital and DNA archive, the drilling and the borehole. Following this, the Lunar Mission One website (specifically the UK Space Agency 2012 Technical Review) was examined to get a more in depth, technical, understanding of the mission and its parameters as an opening source of information.

In the interest of completing the task, it was necessary to source several scientific papers in order to have the information necessary to write the report. Once sources were obtained, notes were taken on each paper to collect the information of interest. This information could then later be used and referenced appropriately.

In order to undertake the research for the project, specific research orientated websites were used to search for the resources required: Google Scholar, Web of Knowledge, Science Direct, as well as other reputable sources including NASA and the ESA.

To further the access to scientific papers outside of the university, a VPN was issued that allowed remote access to the University of Baths subscribed journals. This allowed sources to be found from anywhere with internet access making the research process easier.

The 2012 UK Space Agency Technical Review of Lunar Mission One identified landing gear energy absorption to be a top technology risk for the mission during their analysis. [1] For this reason it seemed important to investigate the energy dissipation methods and technologies that exist as well as any others that may reduce the chance of mission failure.

Energy dissipation is significant for the successful landing of the spacecraft as too rapid dissipation could cause a large force to be exerted on the lander, potentially damaging the contents such as the drill. Additionally, if one of the landing struts were to critically deform, the lander could lose balance and tip over.

A soft landing is required such that the lander and its contents remain functional for the research on the Moon. The lunar dust provides a limiting factor in the descent of the craft however, as the lander cannot thrust below ~ 10 metres due to the amount of dust that would be swirled up from the surface, that could tamper with or damage instrumentation on the lander. This means that in the final seconds of descent the craft will accelerate, and in doing so will build up kinetic energy that will need to be dissipated.

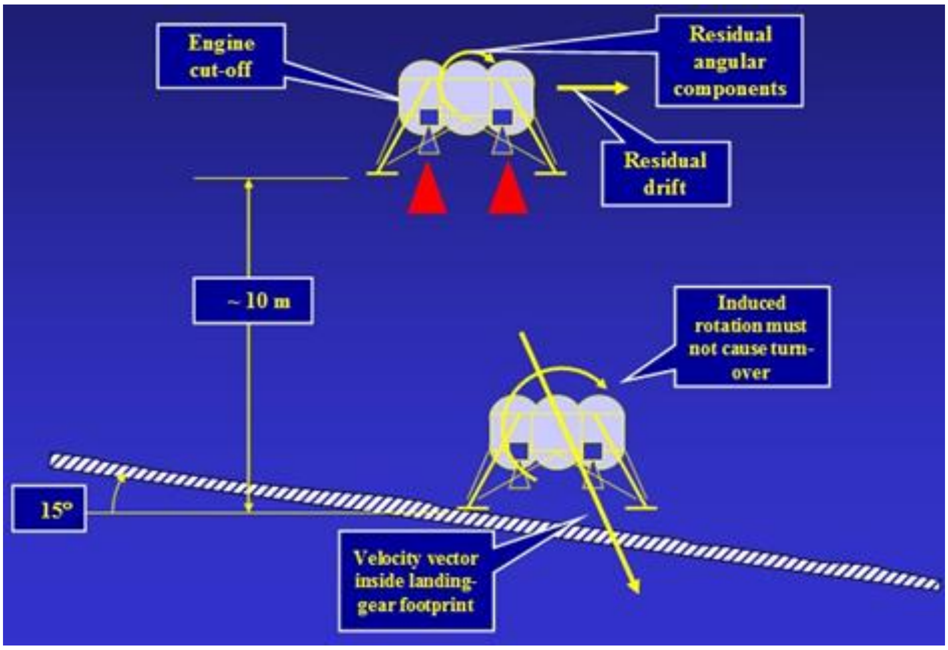


Fig. 1: Touchdown Dynamics [1]

Increasing the amount of time energy is dissipated over, or through another medium, will reduce the resultant force on the lander. This will mean a more reliable and lower risk landing procedure. This can be achieved through several possible technologies including airbags and impact dampers such as aluminium honeycomb or foam, within the struts. Furthermore, finding reliable mechanisms for the landing struts deployment will aid in a successful landing procedure.

Airbags

As explained by Liu R et al. [2], an airbag-type impact damper, with a lander inside, uses air as an impact absorption element. This reduces the resultant force on the lander inside making for a safer landing. Airbag-dampers have good performance for impact absorption, but rebound many times and the pose of the lander is difficult to control. This increases the need for a device to adjust the pose of the craft which increases implementation difficulties and failure risks.

For Lunar Mission One it would seem unsuitable to use airbags as despite their good performance as impact absorption, the possibility of the craft rebounding and having an unstable pose may cause too great a risk to it landing orientated correctly. Considering the accuracy required to land at the Shackleton crater within a $100m^2$ area it seems especially important that landing precision is prioritised. The landing site requires sufficient sunlight exposure and an airbag-type damper may be too likely jeopardise this.

Legged-Type Impact Damper

Liu R et al. [2] explain that the legged-type damper works by containing cushioning materials inside the lander's legs. The material inside crumples upon impact, dissipating the kinetic energy of the lander and allowing it to land safely. Compared to the airbag-type damper, the legged-type is advantageous in terms of stability for landing pose, has a high reliability, is free of rebounding and has a re-adjustable capability. It has been concluded that a Lander of legged-type is more reliable and suitable for landing on a more complex environment [3-5], which bodes well for Lunar Mission One – potentially lowering mission complications and failure risks. Alongside a surface sensory system that can detect the geometry of the ground below, (such as LiDAR) the landing procedure could be effective.

The legged-type impact dampers seem a better alternative than airbags for Lunar Mission One due to their effective absorption and pose capabilities – necessary to stop the impact and keep the lander upright.

- **Aluminium Honeycomb Damper**

Liu R. et al [2] explain that the aluminium honeycomb damper is a two-dimensional cellular material that is an ideal cushion material due to its low density and stiffness, as well as its controllable deformation capability – something that could be utilised in the lander by modelling the material to the design specification of the lander's dampers. Aluminium honeycomb is a well-tested, effective material making it possess strong possibility for Lunar Mission One. Aluminium honeycomb dampers were used successfully in the "Apollo" lunar landers [6-8]

Testing into aluminium honeycomb dampers was undertaken by Liu R et al. [2]. The types of samples are shown below – all of which have a regular hexagonal cellular structure. 'H' representing honeycomb and '1','2' or '3' indicating the type of sample.

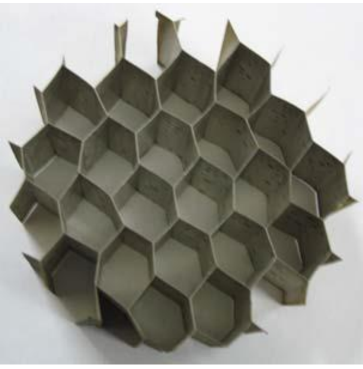
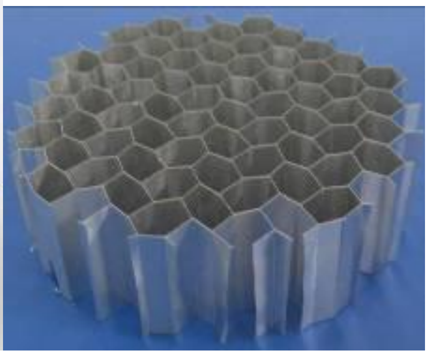
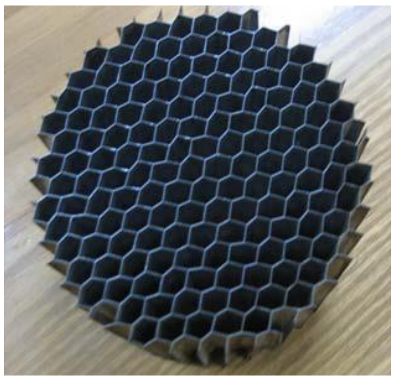
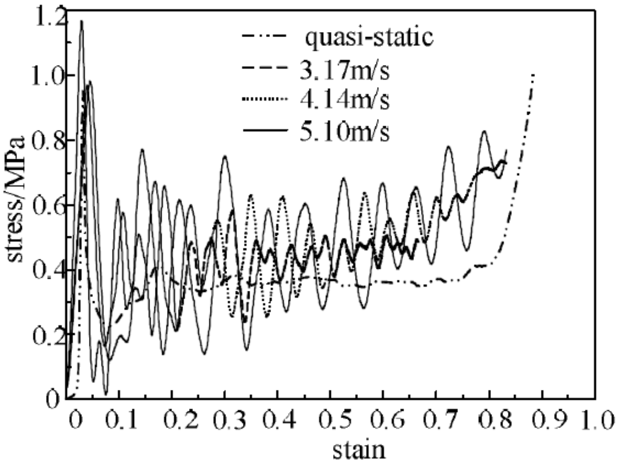




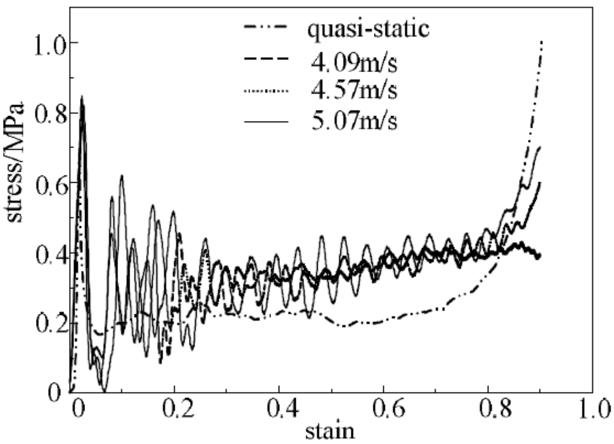
Fig. 2: H1, H2 and H3 samples (left to right) [2]

Below are the crushed samples having been axially crushed to test their material properties. It was concluded that stress-strain curves under quasi-static and impact load coincide very well. This suggests that the compressive properties of the aluminium honeycomb would be largely unaffected by the motion of the lander that is created in its final descent due to the engine cut off. Additionally, it was found that under impact load, the stress in the material fluctuates, particularly at the initial crushing stage, and less so during the steady crush state. Furthermore, the honeycomb was found to have an able deformation capability – a maximum deformation ratio of 0.85.

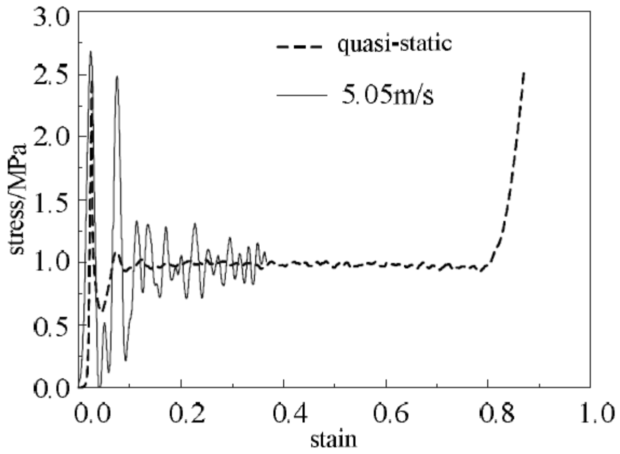
Fig. 3: Crushed samples after experiment [2]



H1



H2



H3

Fig 4: Stress-strain curves of honeycomb samples under quasi-static and impact load conditions [2]

- **Aluminium Foam Damper**

Aluminium foam has several advantages including low density, heat-durability and impact resistance. [2] The ESA undertook comparative tests on aluminium foam and honeycomb and found that the impact energy absorption of aluminium foam per unit weight was greater than that of aluminium honeycomb, and its compressive strength was much lower. [9]

Below are the four types of foam that were used where ‘F’ represents aluminium foam, ‘1’ or ‘2’ represent that the nominal crush strength is either 0.06-0.07MPa or 0.14-0.15MPa, and the ‘C’ or ‘F’ represents coarse-hole foam or fine-hole foam.

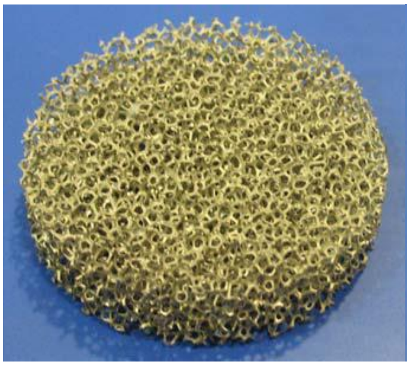
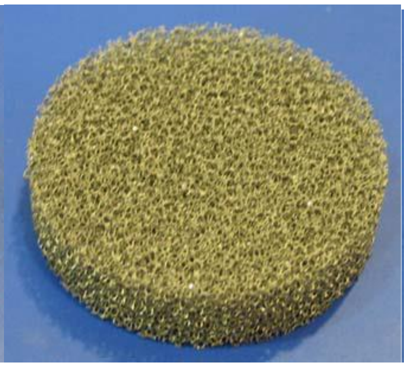
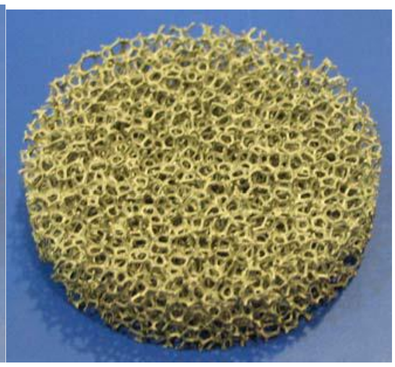
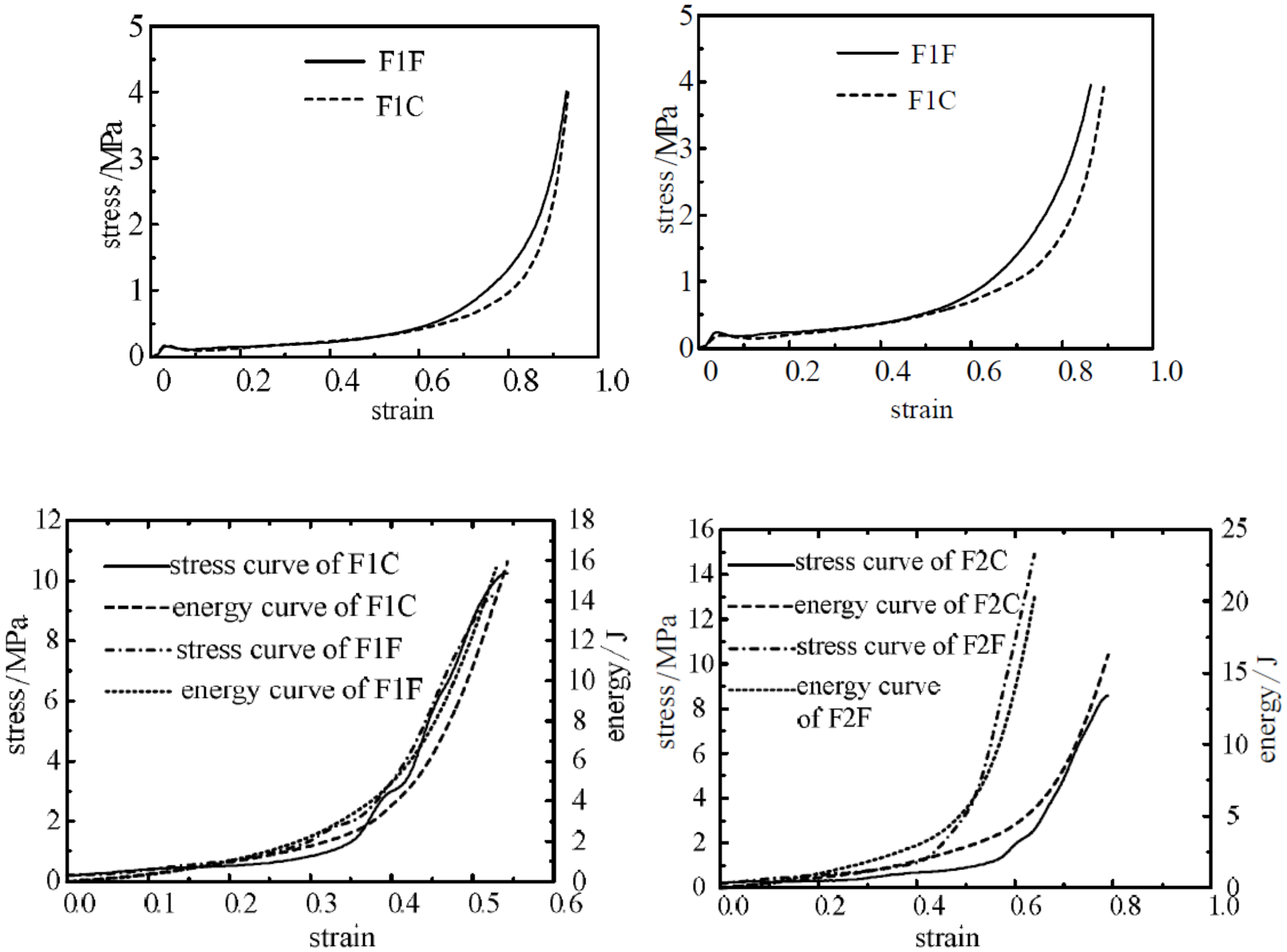





Fig 5: F1C, F1F, F2C, F2F aluminium foam samples (left to right) [2]

Examining the stress-strain graphs for the aluminium foam samples below, it was found that at the first half of the crush stage, stress-strain curves of the coarse-hole aluminium foam samples and the fine-hole samples with the same nominal stress strength coincides very well, but the length with the stable stress variation of coarse-hole foam is slightly longer than that of fine-hole foam which indicates the coarse-hole aluminium foam has greater deformation and energy absorption capabilities [2]. This can be observed in the graphs below as the fine aluminium foam (dotted line) follows a similar trend but remains at a lower stress until a higher strain.

Fig 6: Stress-strain curves of foam samples under quasi-static and impact load [2]



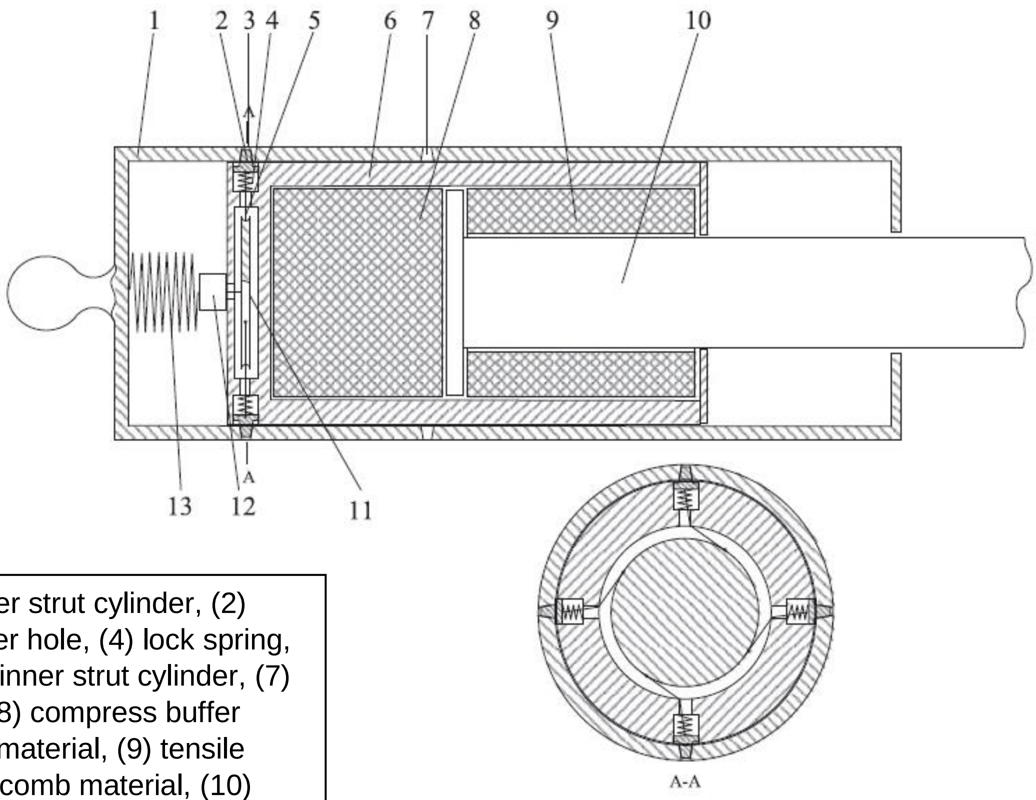
It was concluded from testing that the coarse-hole aluminium foam has greater deformation and impact energy absorption capabilities so it is suitable for an impact damper using aluminium foam. This implies that aluminium foam could be a preferential material for dampening the landing of the Lunar Mission One lander. It is important to consider however that the aluminium honeycomb damper is still effective and has been used more in the past. It may be worth considering what would be a better choice once the specifications of the craft have been finalised to see what would be an optimum solution, which may be aluminium coarse-foam dampers.

Lockable Landing Mechanism

Lin Q. et al. [10] identify that the traditional structure of the deployable and lockable mechanism on soft-landing gear system is complicated and unreliable. If the landing legs cannot deploy successfully, it could bring about a catastrophic result to the Lunar Mission One lander so it is necessary to reduce mission risk as much as possible.

In the traditional landing mechanisms, the compression assembly and locking assembly are separate in the landing legs. The compression assembly would set up the point of compression, and in addition to this the compression model is more complicated. Also, if the whirlpool spring in the locking assembly encountered a failure, it could lead to the failure of the deployment of the landing legs. The overall structure is complicated and the reliability is lower.

The new mechanism proposed aims to tackle the problems of complexity and unreliability. The mechanism works as follows: 1) Compression - inner strut cylinder puts bolts into holes by the elastic force of the locking spring, compressing it into the



Key: (1) Outer strut cylinder, (2) bolt, (3) upper hole, (4) lock spring, (5) rope, (6) inner strut cylinder, (7) lower hole, (8) compress buffer honeycomb material, (9) tensile buffer honeycomb material, (10) Piston rod, (11) rotary disk, (12) stepping motor and (13) high strength spring.

Fig 7: Inner strut cylinder mechanism [10] outer cylinder 2) Deployment - once it reaches orbit, stepping motor makes the rotary disk spin which drives the bolts to be retracted and make the mechanism unlocked. The high strength spring then pushes the inner cylinder outside. 3) Locking: High strength spring elongates to a position where the bolts lock at a lower hole, completing the deployment.

Conclusion

If the lockable landing mechanism were integrated with either the aluminium coarse-hole foam, or aluminium honeycomb damper, and effective landing mechanism could be found for Lunar Mission One. These technologies seem potentially viable, however as further specifications of the mission arise a more thorough analysis may be needed. Additional factors such as cost, may influence the optimum landing solution and new developments in landing technologies may be considered as they are engineered and created before the building of the Lunar Mission One lander. Presented are preliminary possibilities of what may prove as useful assets as part of the landing procedure.

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