PocketPad™: Concept for an Expendable Safe Lander Touchdown Accessory

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The PocketPad™ is a concept for an economical, light weight, disposable, one-time-use only, instantly deployable landing pad that is stowed in the lander itself, and autonomously deployed on site, just before touchdown. The PocketPad™ purpose is to create a buffer between the natural, unimproved extraterrestrial surface and the lander thruster exhaust plume to prevent production of high energy dust and debris that can hamper lander safety. The PocketPad™ also creates a safe dust free zone for cargo and astronauts as well as any high value assets in the vicinity of the landing zone. Merits and challenges of the PocketPad™ concept for landing on any extraterrestrial surfaces, especially in a low gravity and vacuum or low pressure environment as is present on the Moon, Mars, or the asteroids are explored.

Nomenclature

CC	=	Contour Crafting
EDL	=	Entry, Descent and Landing
IFR	=	Instrumental Flight Rules
ILS	=	Instrumental Landing System
LEM	=	Lunar Excursion Module
LIDAR	=	Light Detection and Ranging
NASA	=	National Aeronautics and Space Administration
VFR	=	Visual Flight Rules

I. Introduction

Safe and stable landings are essential for landing crew and cargo on pristine, remote regions of extraterrestrial surfaces. Hyper velocity surface debris, consisting of rocks and dust, raised by the exhaust plume of the main lander engine thrusters on natural, unimproved terrain pose a hazard, not only to crew and exposed high value assets in the vicinity of the lander, but could also severely damage lander underbelly systems and components, especially making undercarriage elements, landing legs, exhaust nozzle or fuel tanks, vulnerable to damage from retro-debris impacts and ricochet effects. Current thrust levels of proposed lander propulsion systems, especially those heavy landers, impart forces on extraterrestrial terrain that easily exceed the regolith bearing capacity, rupturing and cratering the pristine unimproved surface, and in the process, creating extremely dangerous hypervelocity debris.

NASA has proposed projects to construct sturdy, serviceable landing pads on the Moon to support multiple sorties to the same location, but this effort is directed toward building permanent structures and would require complex robotic operations and equipment to build and commission.

The PocketPad™ concept proposes to eliminate the complexity and elaborate redundancies associated with the construction of a solid, permanent landing pad while providing the safety and security for a safe landing by deploying a specially designed landing mat that is compactly stowed on the lander itself, and deployed over pristine, unimproved lunar terrain, just before lander touchdown. The PocketPad™ has the potential to greatly decrease many of the risks associated with landing a spacecraft by providing a rapidly deployable landing pad that results in a smoother, dust-free zone around the lander. Not only can this technique aid us on our Moon for primary lander missions in remote regions under low gravity and vacuum conditions, but this strategy could also be applied to many other extraterrestrial surface that are proposed to be explored.

II. Background to the Problem

The Apollo Program provided much information about the lunar environment, but one key issue that plagued astronauts was the lunar soil, or regolith. Lunar "dust" caused major problems to the Apollo lunar missions where fine

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particles were caught in spacesuit and equipment seals, altered radiative heat transfer properties of the spacesuits adversely, tracked back into the lunar excursion module (LEM) causing adverse health effects to the astronauts (Figure 1), and clung to everything it came into contact with. [Cooper etal., 2008] Research done on lunar dust particles have shown that the finest particles are just microns in size while having a texture as coarse and abrasive as broken glass (Figure 2). [Taylor 2008]

Figure 1: Photo of Astronaut Eugene Cernan covered in lunar dust that was backtracked into the lunar excursion module.

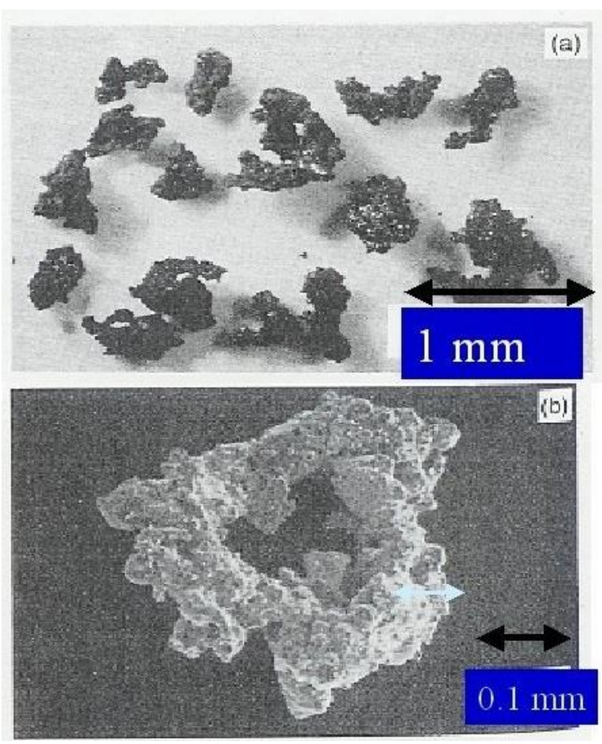

Figure 2: Samples of returned lunar regolith. Lunar dust is generated by micrometeoritic impacts over geological time in a process known as "gardening."

Lunar dust and debris create a much greater danger when interacting with lunar landing thrusters. Dust is propelled outward in all directions at hypersonic speeds causing potential damage to its surroundings and to the lander itself. The Apollo crew reported dust and energetic debris shot outward from the pristine, unimproved lunar terrain during the lander descent and landing phases. The Mars Science Laboratory (MSL) Curiosity Rover used a sky crane (Figure 3) to prevent dust and debris from damaging its instruments, and yet it was discovered that a wind sensor was still damaged during the touchdown phase. [Amos 2012]

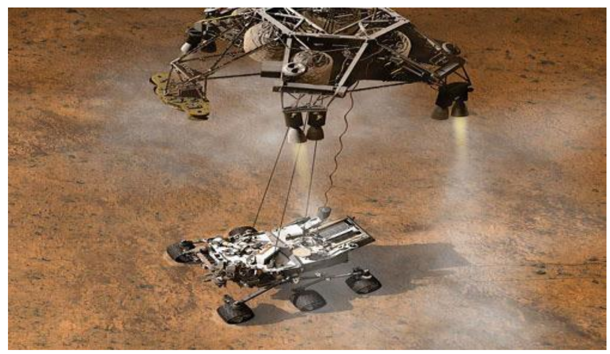

Figure 3: Mars Science Laboratory Curiosity Rover and the Sky Crane at touchdown.

Another effect of thruster interaction comes in the “sand blasting” effect where clouds of hypersonic dust are sent in all directions. This phenomenon was conclusively verified during the Apollo 12 mission that touched down in the vicinity of the Surveyor 3 robotic lunar lander. The touchdown of the Apollo 12 landing module about 160 meters away sent an energetic spray of dust and debris flying across the lunar surface sand-blasting the side of the Surveyor 3 facing the lander module. Component samples from the Surveyor 3 lander were studied and it was observed that the spray of dust contained grains of sand of about 60 microns in size that traveled at hypersonic velocity, drilling through paint and fracturing the wall of the craft. [Hintze etal., 2011]

A more recent and observable example of the sand blasting effect can be observed with rocket landing tests performed here on Earth. The Amazon company Blue Origin has released video footage of their New Shepard reusable rocket tests being performed in the desert. Figure 4 shows a snapshot of the New Shepard rocket descending into the desert sands, creating a massive dust cloud around the landing area. These rocket tests require non-shielded observers to be no less than half a mile to a mile away to prevent injury or death. In extraterrestrial terrain with little to no atmosphere and gravity, hypersonic debris projectiles can reach distances as far as 6-8km (3.7–5 miles) from the lander, following Newtonian trajectories.

Figure 4: Amazon Blue Origin's New Shepard landing demonstration creating a massive dust cloud.

Simulation models have been able to recreate the interactions between the rocket plume and lunar regolith. Figure 5 shows the number density of particles from the thruster exhaust with respect to altitude and distance. This is coupled with the model in figure 6 showing the mean free path of exhaust particles increasing as distance increases from the center of the plume. The thrust simulations are then able to simulate the effects they have on the lunar surface in figures 7 and 8 which display surface erosion rate with respect to distance and dust behavior to the rocket plume, respectively. In this case, Morris tests the effectiveness of using a fence to block surface dust from spraying outward. [Morris, 2011]

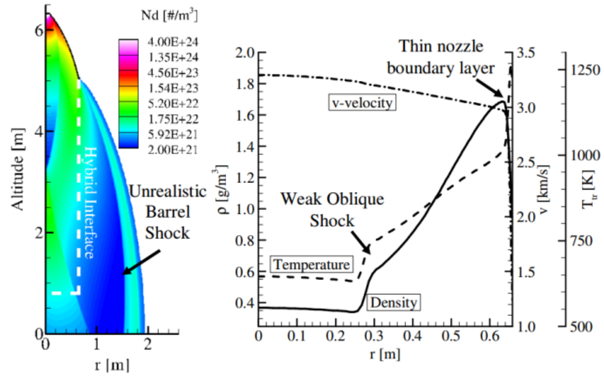

Figure 5: (Left) Number density contours. (Right)Macroscopic properties at the exit plane of the nozzle.

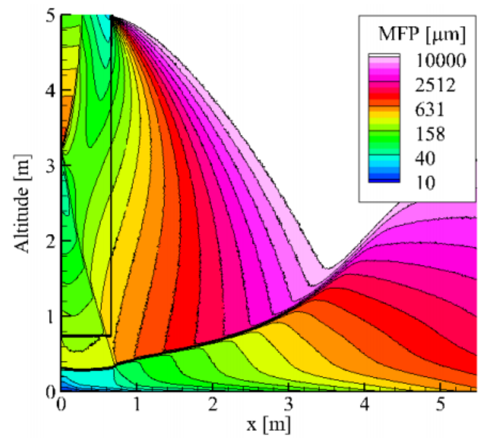

Figure 6: Gas mean free path contours in the near field.

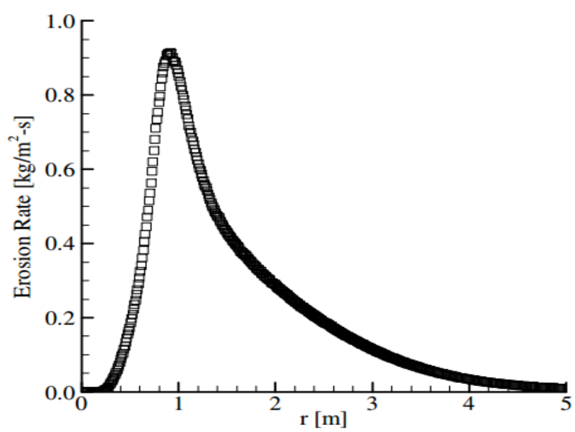

Figure 7: Erosion profile for axisymmetric hover 5 meters above the lunar surface.

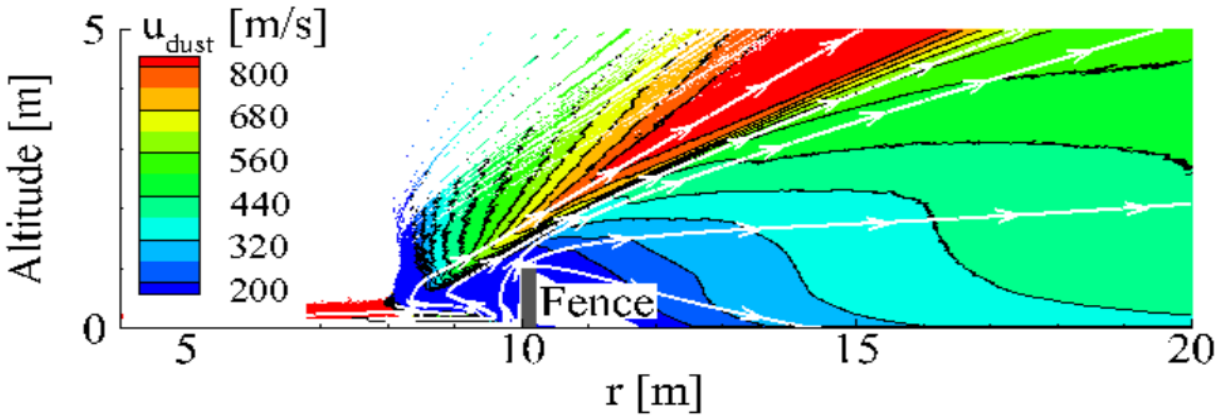

Figure 8: Horizontal velocity contours for the dust grains interacting with a deflection fence placed 10m from the jet axis

III. Current Solutions

NASA has proposed landing pad projects employing robotic construction systems such as the USC Contour Crafting (CC) robot (Figure 9) to construct solid, serviceable landing pads on the Moon (Figure 10) to support multiple sorties to the same location, but this effort is directed toward building permanent structures and would require extensive planning, equipment, and complex robotic operations. [Khoshnevis etal 2005,2012 Thangavelu etal., 2012] Robotic construction systems will need supervision and maintenance. Safeguards will also need to be taken into account to prevent and protect the robots from damage throughout its mission and service lifetime. The PocketPad™ concept is primarily meant for initial lunar landings when such permanent structures are not yet commissioned. Such landings can occur in various regions across the lunar globe. In cases where sensitive sites such as exposed observatories or historical preservation of zones around the Apollo landing sites are concerned, new methods are sought to prevent disturbance of the pristine lunar surface as well as artifacts and even humanity's first footprints and tracks due to future routine lander operations.

Figure 9: USC Contour Crafting Concept offers a robotic construction system to build up lunar infrastructure.

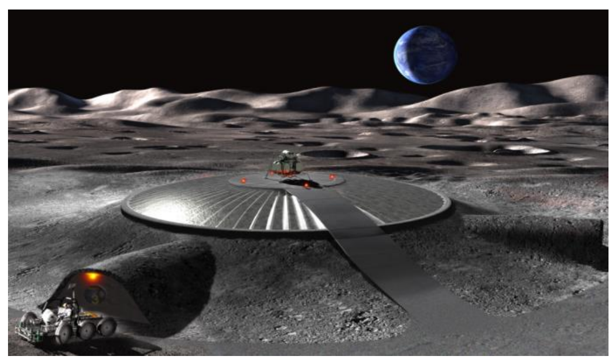

Figure 10: Concept photo of the USC Permanent Lunar South Polar Landing Pad funded by NASA for repeated landings with heavy payload.

IV. PocketPad™

The PocketPad™ offers an economical and instant method to introduce a dust-free zone for extraterrestrial lander missions that touchdown on pristine, unimproved terrain. The importance of a dust-free zone around the lander is paramount as it allows astronauts, equipment and autonomous vehicles in the vicinity of lander operations to work unimpeded by dust and lethally energetic debris, especially in the low gravity lunar, Martian, or asteroid environments. Absent an atmosphere, and without curtailment systems in place, dust and debris will follow Newtonian ballistic trajectories, and can have lethal effects many kilometers from the lander touchdown sites.

For the PocketPad™ System to function as proposed, several assumptions and requirements must be made. Prior to touchdown, the lander must acquire a high resolution image of the surface to predetermine a natural, relatively flat area for landing. The PocketPad™ design and construction of materials, configuration, and patterns should be compatible with the proposed extraterrestrial landing terrain. The lander's descent rocket plume should not interfere with the PocketPad™ trajectory during the deployment maneuver. Lastly, future landers can be assumed to be smaller or much larger than the Apollo Lunar Module, and the PocketPad™ must be customized for each mission to accommodate this requirement.

Construction

The PocketPad™ is to be constructed here on Earth and stowed in the undercarriage of the lunar lander. Ideally, the construction of the PocketPad™ would entail materials that are very lightweight and flexible such as Kevlar, carbon-carbon fibers, refractory materials, and metal fiber enhanced composites. The main components for the PocketPad™ will include a core area containing refractory fabric to withstand thruster temperatures, an outer area that is thinner and made of penetration resistant materials, and an inflatable, stiff outer edge to direct the thruster exhaust upward and away from the loose debris in the pristine, unimproved terrain. It is important to note that materials and deployment and anchoring methods will vary depending on the mission where variables such as the size of the lander and bearing capacity of the terrain must be taken in to account. Sturdier materials and a more robust build may be used for harsher environments like Mars while lighter and thinner materials may be prescribed for smaller or lighter touchdown missions like the Moon or asteroids. A sample mass estimate for the NASA reference Altair lunar lander with a footprint of approximately 14.5 meters would have a PocketPad™ dimension of 30 meter diameter. Assuming a pad density of 0.5 kilograms per square meter plus 50 kilograms for an avionics package, the system will have a total mass of roughly 400 kg. The ideal PocketPad™ design will find ways to decrease mass penalty even further and is part of ongoing investigations. A schematic of the PocketPad™ is shown in Figure 11.

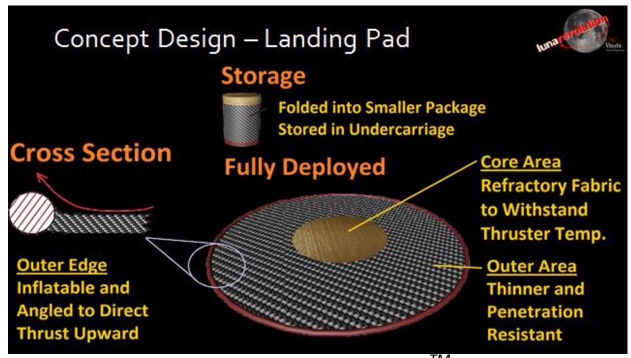

Figure 11: Salient features of the PocketPad™ Concept

Conceptual Deployment Sequence

A conceptual deployment sequence for the PocketPad™ is numbered below and shown in Figure 12.

1. Folded into a pod and stored in the undercarriage of the lander
2. PocketPad™ is deployed on the pristine, unimproved extraterrestrial surface roughly 300 meters and 60 seconds before lander touchdown.
3. PocketPad™ pod is spin stabilized as it begins to unfold and the outer stiffener ring is inflated to achieve full-out configuration during the deployment sequence.
4. PocketPad™ touches down onto lunar surface and the avionics package is activated.
   a) PocketPad™ self-anchors onto the surface
   b) The outer rim of the PocketPad™ lights up giving a clear visual aid to the lander pilot.
   c) LIDAR will establish a link and communicate continuously with the lander as it guides the lander for an automated landing.
5. The lander's main engine is cut-off roughly TBD meters above the PocketPad™.

6. The lander freefalls for the remaining TBD meters to touchdown onto the PocketPad™

This sequence is very preliminary and needs further study and refinement.

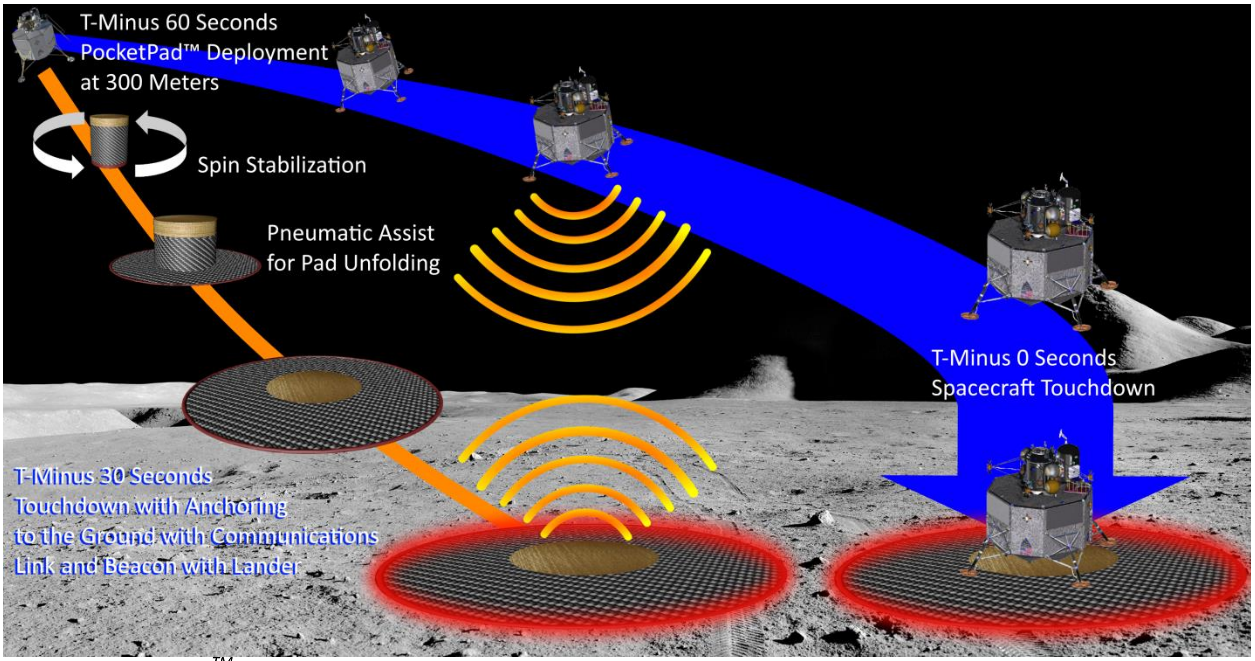

Figure 12: PocketPad™ deployment sequence, from stowed underbelly configuration to fully deployed pad relies on a rapid series of automated events that provides a dust-free landing pad for the lander, just before touchdown.

Challenges and Limitations

The PocketPad™ will add a payload penalty to the craft. The deployment and unfolding sequence must be precise and timely. The deployment of solar sails offer some data on stowage and unfurling mechanisms [Davis 2015] but the PocketPad™ deployment is more complex and will require several levels of simulations and tests. Anomalies may occur during deployment such as attitude control and interactions between the PocketPad™ and descent engine as well as entanglement while unfolding which must be avoided. Lastly, the PocketPad™ is not intended for multiple uses as the fabric becomes unserviceable after the primary deployment. It is conceived as a one-time-use only accessory for safe lander touchdown on pristine, unimproved terrain.

The PocketPad™ concept architecture suggests what such a system may be capable of, and extensive studies and tests are required to determine the optimal ways and methods to construct and deploy the PocketPad™.

Future Study

There are a multitude of combinations of materials that can be used to construct the PocketPad™ and research is warranted to find the materials best suited to the mission as well as the best configurations and contours of a fully developed system. The optimum sequence and operations strategy needs further investigation. Fabric flutter, deviations, correct spin momentum, and interference avoidance with the landing thruster plume during the rapid deployment sequence must be studied and fully simulated before such a system can be commissioned. Once the PocketPad™ has touched down onto the surface, a self-anchoring system mechanism may need to be developed. Compact stowability and reliable, surefire deployment will need thorough study and development. In another expanded application for this technology, large expanses of unimproved terrain may be covered with very lightweight, impermeable fabric, well in advance of surface activity and just before lander touchdown. Such a strategy could prevent dust from fouling up EVA suits and equipment while allowing boring for core samples or drilling to establish foundations or sturdy anchors for a variety of structures.

V. Summary and Conclusions

As private and public companies express greater interest in space and extraterrestrial activity, new techniques must be established for safe landings on natural, pristine, unimproved terrain with minimum disturbance to exposed payloads and sensitive equipment that may already be on site in the proximity of the landing zone.

A stowable, rapidly deployable landing pad will greatly decrease the many risks associated with landing a spacecraft on extraterrestrial surfaces. After deployment, the PocketPad™ will use LIDAR communications to reduce human error by using an autopilot and Instrumental Landing System (ILS) for landing. Lander pilot will retain command and control, if needed, and Visual Flight Rules (VFR) override can be initiated for any reason as the pilot sees fit during the final phases of descent and touchdown.

The PocketPad™ provides a rapidly deployable landing pad resulting in a clean and dust free zone under and around the lander. Not only can this technique aid us on our Moon for primary lander missions in remote regions under low gravity and vacuum conditions, but this strategy could also be applied to any other extraterrestrial surface that is proposed to be explored.

Acknowledgements

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