Moon Dialogs Salon 2
The Implications of Dust for Resource Contention and Lunar Policy
7 May 2020

The Moon Dialogs Research Salons seek to cultivate thought leadership on lunar surface coordination mechanisms to accelerate a peaceful and sustained presence on the Moon. The initiative will focus on advancing concrete approaches to operating standards, norms, and economic foundations, with an emphasis on applied and 'bottom-up' approaches, and creating opportunities for voluntary coordination between and amongst industry, government, and academia alike.

Presentation: Phil Metzger

The second Moon Dialogs Research Salon virtual event took place on Thursday, May 7, with a presentation from Phil Metzger, a planetary physicist at the University of Central Florida, dust dynamics expert, and co-founder of NASA's KSC Swamp Works. Dr. Metzger's presentation focused on technologies for planetary surfaces (including mining, manufacturing, and construction using space resources), and the policy implications of dust on the contention for lunar resources and cis-lunar activities.

Phil Metzger began the presentation with an overview of the phenomena and its importance, stressing that dust ejected by rocket exhaust can interfere with actors' activities and should be mitigated. Rocket exhaust effects on the Moon differ from those on Earth and Mars, since the vacuum environment allows rocket exhaust to spread out faster and very widely, instead of a columnated jet digging a deep crater into the soil. This exhaust picks up dust particles, ejecting them in a thin sheet several degrees above the local horizon at a high velocity. The best data available on this phenomenon comes from studying video footage from lunar module landings, which depict objects ejected at high velocities from the lunar landers (including fist-sized rocks at 60 mph). Signs of erosion taking place further away from the landers also come from the photos taken by NASA astronauts on the Moon, which allow scientists to roughly estimate that about 2 tons of lunar soil was ejected during those landings.

Why is this important? Apollo 12 astronauts landed near the *Surveyor 3* spacecraft, and returned pieces of this lander ("coupons") to study the long-term exposure effects of the lunar environment on the spacecraft. The landing of Apollo 12 sandblasted the Surveyor, scouring its surface material with at least three cm^2 of dust and leaving deep pits and cracks containing lunar sand grains. Fortunately, because the *Surveyor 3* was in a crater below the spray line, that damage was just 0.1% of what it would have been if it had been exposed to the direct spray. Experiments in sandblasting materials with lunar dust have followed, revealing the severe damage it can cause to glass, materials, and hardware, and raising the need to ensure that the ejecta does not damage the hardware of any space actor on or around the Moon more than what the natural environment would normally cause; or at least reduce it to some acceptable level.

Importantly, dust from a lunar landing will travel over the entire surface of the Moon, and some of it will entirely escape the Moon. Depending on the propellant and the size of the lander, the denser the gases will be and the faster the ejecta will go. Implications for the NASA Gateway in cislunar orbit include that ejecta will impact Gateway on a regular basis.

How much ejecta will cause damage to lunar and cis-lunar activities, including physical and/or economic harm? The erosion rate of lunar landings and takeoffs has yet to be concretely predicted. According to his predictions, a 200 ton lunar lander will blow 1,000 tons of ejecta. He stressed that these figures may be somewhat off, but they are significant enough for policy discussions. Even landers of the size proposed in the Google Lunar XPrize competition demonstrate ejecta more than 20km away from the landing site. Additionally, there are appreciable shockwaves sent from the initial overpressure of rocket landings, and in takeoff, which still needs to be assessed.

In 2011, NASA promulgated Guidelines to Protect Lunar Heritage Sites which included rocket plume issues. A 2 km boundary line was included in the guidelines. Other guidelines included tangentially landing trajectories, plume reflection planes pointed away from heritage sites, landing behind natural terrain barriers, and other rules which recognized that damage to heritage sites are cumulative with each subsequent spacecraft landing. After landing, "hopping" inside the 2 km radius of the site is recommended, so long as this hopping is above 40 meters in height. And, for any actor planning to land on the Moon, a requirement to consult with NASA and to conduct Collision Avoidance (COLA) calculations to assess whether orbiting spacecraft would be at risk of being impacted by the ejecta.

Turning to points of potential contention, Dr. Metzger pointed out the following findings:

- High velocity dust impacts are very damaging to hardware;
- The science and engineering are not yet able to define a safe landing distance;
- The NASA Guidelines set a precedence, defining an arbitrary 2km keep-out zone;[1]
- Larger landers may require vastly larger keep away distances;
- Sensitive equipment may need vastly larger keep-out zones; and
- Some locations on the Moon are far more valuable than others.

These locations which are more valuable include the Peaks of Eternal Light (as discussed in Research Salon #1). In Dr. Metzger's opinion, the most important pieces of real estate in the entire solar system are those locations on the Moon where there are far richer deposits of resources, close to good landing sites, and which are close to sunlight. These are the locations where humanity can begin industry off the planet. These locations are rare and limited.[2]

Dr. Metzger gave a few possible scenarios:

- A State places a sensitive telescope in the center of one of these resource-rich zones as a tactic to force other nations away;

[1] 2 km was later explained as 'just over' the horizon on the Moon, and therefore more protective of hardware downrange.

[2] Dr. Metzger references the work of Kevin Cannon on mapping lunar resources: https://kevincannon.rocks/lunarmining/

- A State quickly puts outposts on all of the best Peaks of Eternal Light adjacent to the best ice fields; and claims they need a keep out zone around each one of them
- A State claims another State damaged its hardware by landing at a location far away;
- Instruments on an orbiting spacecraft are ruined by sandblasting by a lunar lander.

Dr. Metzger concluded with a brief discussion about building landing pads to mitigate these risks. Possible pad building methods include solar-, microwave-, and infrared-sintering, and interlocking pavers. The use of *in situ* gravels and rocks is also possible, but requires complex robotics. And polymer is a simple alternative, but would require maintenance and a lot of mass would be brought from Earth. Regardless of the method used to build landing pads, a number of questions remain:

- Will the building of landing pads be required by lunar actors? If so, when?
- Are landing pads to be internationally shared as a 'commons' amongst actors?
- How large can a lander be without requiring that it land on a landing pad?
- Who will build and maintain lunar landing pads?
- Who would remove defunct landers from landing pads?

Dr. Metzger concluded his remarks at the Salon with saying that we will have to make decisions on dust ejecta norms before we really know all of the information. In doing so, are we going to err on the side of making the Moon easier to access and permitting more ejecta, or, are we going to err on the side of protecting each other's hardware and restricting ejecta?

The video of Phil Metzger's presentation is at https://vimeo.com/418254312

Discussion Amongst Participants

The Research Salon then went into the discussion segment of the program, which fell into the categories below.

Dust creation

In the discussions, participants indicated their acceptance of the fact that dust will have a real physical effect on spacecraft through impacts and collisions, and that it should be incumbent on actors to reduce ejecta as much as possible. Lunar landing pads seem necessary, but will not eliminate all the risks. Participants questioned the extent that operators can be required not to cause dust, and whether landers can be designed (or required to be designed) in ways which effectively minimize dust creation. Participants also recognized that since ejecta cannot be completely avoided, lunar actors will need to decide on some level of risk tolerance in their activities. How does this get decided, and who must be consulted?

Participants explored the concepts of 'harmful contamination' and 'due regard' from the OST with respect to dust and contention. Sentence 2 of Article IX of the Outer Space Treaty speaks of harmful contamination:

> States Parties to the Treaty shall pursue studies of outer space, including the Moon and other celestial bodies, and conduct exploration of them so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter and, where necessary, shall adopt appropriate measures for this purpose.

As no interpretation of 'harmful contamination' has yet been advanced (for dust or otherwise), there may be an opportunity to develop one as the basis for a more concrete discussion. Sentence 1 of Article IX of the Outer Space Treaty also speaks of a due regard obligation:

> In the exploration and use of outer space, including the Moon and other celestial bodies, States Parties to the Treaty shall be guided by the principle of cooperation and mutual assistance and shall conduct all their activities in outer space, including the Moon and other celestial bodies, with due regard to the corresponding interests of all other States Parties to the Treaty.

On the issue of liability, participants wondered whether valuable resource deposits might be subject to compromise by dust and blast effect, and if such a compromise might be seen as an infringement on other actors' activities. Additionally, how might dust effects influence interactions between multiple mobile payloads on CLPS landers?

Safety Zones

Participants also discussed safety zones and safety zone policy. One participant explained that the 2.0 km distance in the NASA Guidelines was based on the fact that, on the Moon, the horizon is approximately 1.8km away. Thus, a 2km distance would assure that a lander is just beyond the horizon and therefore a dust sheet originating from it would "fly over" critical hardware at the near-site.

Safety zones will likely be a complex function of size, activity, sensitivity, and neighbouring activities (which are not necessarily pre-determined). As such, can safety zones be standardized, or will they always be specific to missions and local conditions? Will they be static, or might they need to be dynamic? Some of these questions will be settled by technical insights, but others will require subjective choices based on policy preferences, risk tolerance, and considerations around coordination.

Safety zone policy issues

More broadly for governance on the Moon, on what legal basis will these safety zones be claimed and justified, and how does the chosen legal basis inform or constrain other activities?

Many participants noted the sensitive relationship between safety zones, territorial occupation and the non-appropriation principle. Some questioned whether safety zones are a *de facto* territorial appropriation, which is prohibited by Article II of the Outer Space Treaty. The question was also raised as to whether the NASA 2011 Lunar Heritage guidelines for 2km, really were precedent-setting in establishing safety zones. If they were, some wondered whether this could actually be harmful by incentivizing actors to advocate for larger safety zones than they actually need. They also asked whether the use of safety zones might set a precedent for the broader use of keep out zones, and whether reliance on keep out zones as a policy tool might erode the non-appropriation principle.

Some wondered whether there are alternative options which might be contrasted with the safety zone approach, and whether we are jumping too quickly to familiar solutions.

Lastly, it was noted that the need for safety zones is independent of landing pads, and will persist even with spaceports on the Moon. Others asked whether safety zones are currently being required in the NASA CLPS program, and whether this may further create precedent.

Landing pads

The other major topic of discussion were landing pads and associated policy questions. Participants queried how large a lander must be before it requires a landing pad, or indeed what the specific determinants of such a requirement should be (again planned or neighbouring activities may factor in). Other participants answered that it depends on how much damage is acceptable. Some felt that landing pads must be reusable, and that single use landings pads are counterproductive. It was pointed out that we still don't know even from a technical standpoint the best way to construct landing pads: should we deploy pre-constructed landing pads, build them from scratch, or use *in situ* resources.

In discussions on landing pads, groups shared that while research and development on landing pad technology is growing, there are still no explicit expectations, plans, or standards for how these landing pads should be constructed or maintained. In fact, they felt that many open questions remained, with complex interactions between (as-yet unknown) technical realities, costs, concepts of operations, users, reusability, landing location, operator rights, etc.

The view was expressed that having a plan on the construction of landing pads will help to address dust concerns associated with landing/takeoff. However, it may also concentrate activity to this region, and therefore potentially exacerbate other forms of dust impact.

Others commented that perhaps the international community could agree on where ten or twelve landing pads could be on the Moon, and then work collectively to build them.

Landing pads policy

Numerous questions arose regarding the establishment and maintenance of landing pads, and of access to them. Do we require operators on the Moon to build landing pads, and if so what conditions trigger this requirement? How is the obligation to build landing pads enforced – i.e. what is the "punishment" for not following the requirement? Who builds and maintains the pads? Should we have a common pool to fund all landing pads on the Moon? Who removes defunct landers off the pads? Participants also asked whether lunar actors should share landing pads as a commons.

Of course, any discussion of the requirement for building and using landing pads on the Moon (a shared area beyond national territorial sovereignty) must include a discussion of how norms can arise and how they can be enforced – or why actors would otherwise observe these norms.

What types of consequences would flow from violations of these norms? Stigmatization? Outcasting? Loss of future rights, perhaps include mining rights? Is exclusion from the use of landing pads even possible, or legally permissible under the Outer Space Treaty, especially Art. XII:

> All stations, installations, equipment and space vehicles on the Moon and other celestial bodies shall be open to representatives of other States Parties to the Treaty on a basis of reciprocity. Such representatives shall give reasonable advance notice of a projected visit, in order that appropriate consultations may be held and that maximum precautions may be taken to assure safety and to avoid interference with normal operations in the facility to be visited.

Policy analogs

Are there analogs in the fields of policy and international relations to borrow from? The comment was made that, to the extent that the USA and China might remain the primary suppliers of water, oxygen, and fuel to other actors on the lunar surface, it will remain a duopoly, and that there is a rich history of behavior of duopolists in the U.S. Antitrust literature.

Other questions regarding analogs were posed, including asking whether there are analogs in air traffic and airports which can be transposed to lunar landing pads. The high seas is a common policy analog for keep out zones and other related norms for the Moon, but they are rarely analyzed in depth. Where do they break down?

Reflections and Calls to Action

Based on the presentation and on the discussions afterwards, it seems that dust creation presents a real challenge to actors on the Moon. It may be possible to mitigate dust ejecta through the use of landing pads, but despite best efforts, some dust threats will persist, and subjective tradeoffs and policy decisions will be required.

Promulgating the idea that the use of landing pads, and the minimization of dust, are required, seems necessary – as is socializing the idea that dust is inevitable and must be accepted as the "cost of business" of performing lunar activities. Further discussions on the questions posed to participants, as well as contemplating the scenarios which may lead to conflicting interests, is warranted.

Calls to action

- Can the community advance a working draft definition or interpretation of harmful contamination and/or due regard?
- Can lunar actors accept the notions that dust is inevitable, and/or that the minimization of dust is required and in the best interest of all.
- Can lunar actors accept the notion that safety zones are also in everyone's best interest (possibly even a public good)?
- Does the 2km safety zone seem acceptable to actors? And what are the limits of this safety zone – is it an exclusion zone, where others are not to transgress into? Is there a difference between safety zones and keep out zones?
- Can lunar actors decide on the requirements for landing pads, and/or the number and/or locations of landing pads? Can lunar actors develop some basic norms regarding landing pads?