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Lunar Tourists – Passing the Driving Test

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ABSTRACT

Space tourism is a major enabler of affordable responsive space, through providing the necessary markets for the resulting economies of scale to justify reusable launch vehicles and spacecraft. The space tourists are themselves the payloads that close the economic business case. Space tourists will follow where the pioneering astronauts have led, and this will eventually result in lunar space tourism. Already, initiated and motivated by the former Google Lunar XPRIZE competition, several private teams have been constructing rovers and hoppers designed to operate on the lunar surface, which, though un-crewed, demonstrate the main technologies that can lead to the lunar tourism opportunities. Who is going to decide the rules of the road for the future robotic and crewed transportation on the lunar surface? What is the legal and regulatory framework, and is it ready to handle these new circumstances? Where will the future private robotic or crewed lunar vehicles want to go, and is there a need to protect the most popular heritage sites from tourist overload?

KEYWORDS: Space tourism; Lunar tourism; Google Lunar XPRIZE; Heritage Site Protection; Regulatory situation; Gateway Earth; Lunar legacy; ForAllMoonkind; Apollo

1. INTRODUCTION

Commercial exploration of the Moon, using both robotic craft and eventually space tourism vehicles, will begin in the relatively near future. Already, thanks to the rules of the former Google Lunar XPRIZE competition (GLXP), there has been a need to consider what, if any, guidance is needed for these future lunar explorers. What indeed would be required in order to pass a lunar driving test? This paper brings together the lessons learned from the judging of the GLXP competition, and records these insights, while considering what future steps are still required to protect lunar heritage sites from potential damage when the new phase of lunar exploration and development begins. We shall need to drive carefully, when moving about on the lunar surface!

2. LUNAR TOURISM

Space tourism has been around since 2001 when Dennis Tito took his trip to the International Space Station (ISS), and arguably from even earlier (depending on definition) when Akiyama (1990) and Sharman (1991) each flew to the Mir space station in the Soviet era. Following Tito, 6 more space tourists each took a Soyuz trip to the ISS in the period up to Sept 2009, when Guy Laliberté flew the last space tourism flight to date. In fact, one of them, Simonyi, even made two flights. Since then, there has been a hiatus, mainly caused by the supply constraint, following the retirement of the Space Shuttle fleet, that meant that all Soyuz craft were needed to take government astronauts up to the space station, with no spare seats for tourists. The demand for this low Earth orbit (LEO) space tourism has not gone away, even at the potential ticket prices in the tens of millions of dollars. Up until now, there have not been any non-Soyuz ways of getting space tourists into orbit, but that should change once the commercial vehicles, eg the SpaceX Dragon craft, have been certified to carry crews.

Meanwhile, there has been a long development phase for a sub-orbital space industry, with the Blue Origin New Shepard and the Virgin Galactic SpaceShipTwo perhaps being the leading contenders to provide offerings. The sub-orbital experience will be very much cheaper than the LEO proposition (around $100,000 per ticket), but of course will provide only a short duration of spaceflight, somewhat akin to Alan Shepard's first fifteen-minute spaceflight which kicked off America's entry into the space race in 1961. Current estimates of the start date for this low-price version of space tourism are 2019/2020.

Various market research studies have been carried out looking into the demand for a range of different kinds of space tourism (eg Ref 1), and in general the price elasticity of demand is such that folks want to go farther, and stay longer, in space (although probably not for more than two weeks), and they accept that the prices will reflect the increasing difficulty of achieving this. There are proposals for a space hotel in Geostationary orbit (GEO) (Ref 2), which would therefore place the tourists 100 times farther out into space than has been the case for any astronaut in half a century. But the jewel will be lunar tourism, when space tourists can go to the Moon, initially only so far as to Lunar orbit, but eventually to a lunar

landing. Andy Weir's latest book (Ref 3) specifically describes in precise detail a lunar colony "Artemis" which has been erected nearby to take advantage of the tourism potential of Apollo 11's landing site Tranquility Base.

There is a certain inevitability about all of this. Sub-orbital space tourism leads to orbital LEO, which leads to orbital GEO, which leads to lunar orbit tourism, which leads to lunar surface tourism. Tourists eventually follow where explorers have led. Just go to Everest these days. Or Antarctica, or even down to the wreck of the Titanic. Fig 1 shows one of the Apollo landing sites, in a photo taken relatively recently from the LRO spacecraft orbiting the Moon. We can see all the artifacts from the 1972 mission still in place as a natural tourist attraction for the future. You can even still see the tracks and footprints from the lunar rover and the Apollo 16 crew as they went about their business. Such sites will be major tourist attractions in the future – maybe even leading to tourist overload.

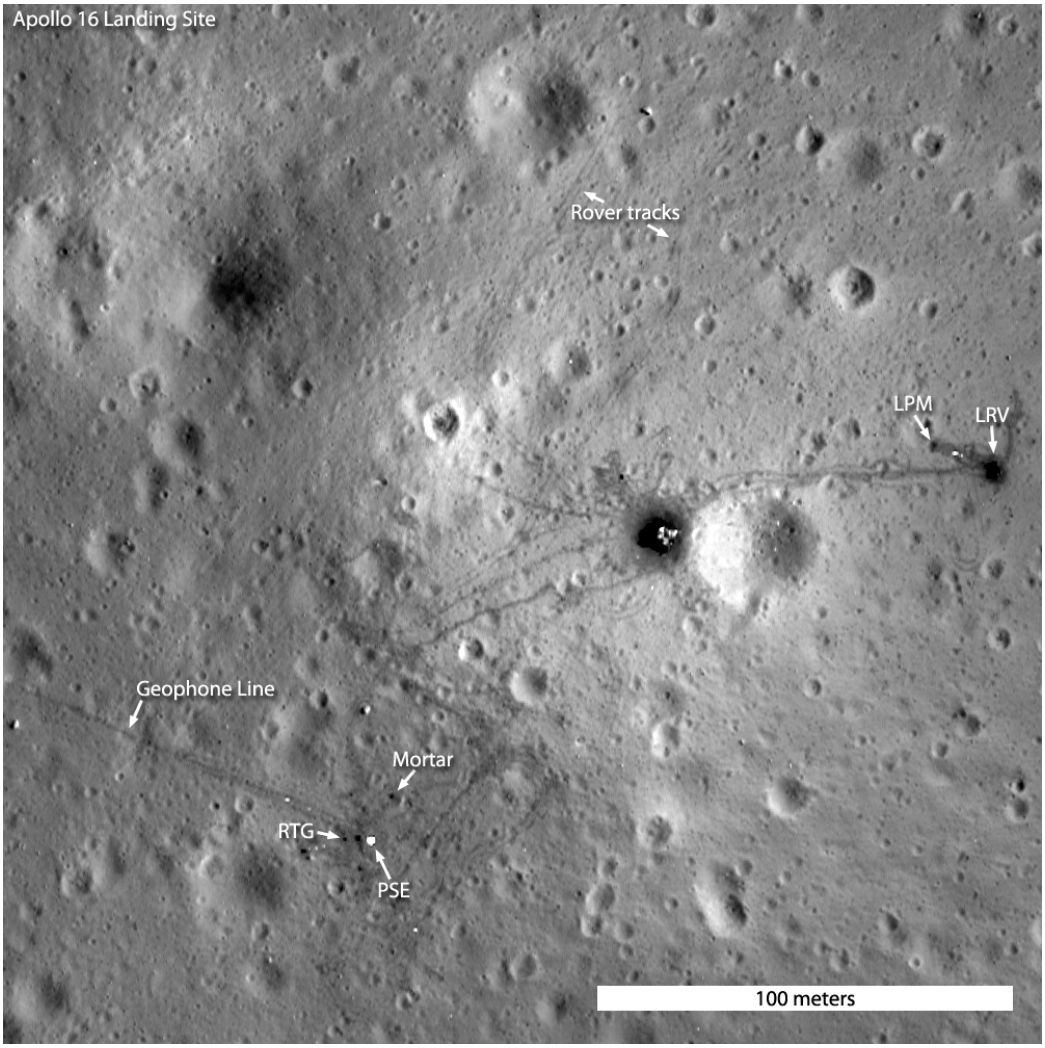

Fig 1 Site of Apollo 16 landing, showing tracks and artifacts left behind by Young and Duke after the 1972 mission. Image taken from the orbiting lunar satellite LRO, 40 years later, in 2012.

Credit: NASA

Several commercial lunar businesses have been proposed, and some are already relatively well developed. The Google Lunar XPRIZE kick-started a robotic landing ability which will probably lead to several teams taking payloads to the Moon on a regular basis (to be discussed in Section 4 below), Golden Spike proposed a commercial passenger-carrying lunar lander, and SpaceX (Fig 2) is offering a circum-lunar flight carrying two (very rich) tourists in a modified Dragon spacecraft, one of whom has apparently already committed to paying the ticket price of $150M.

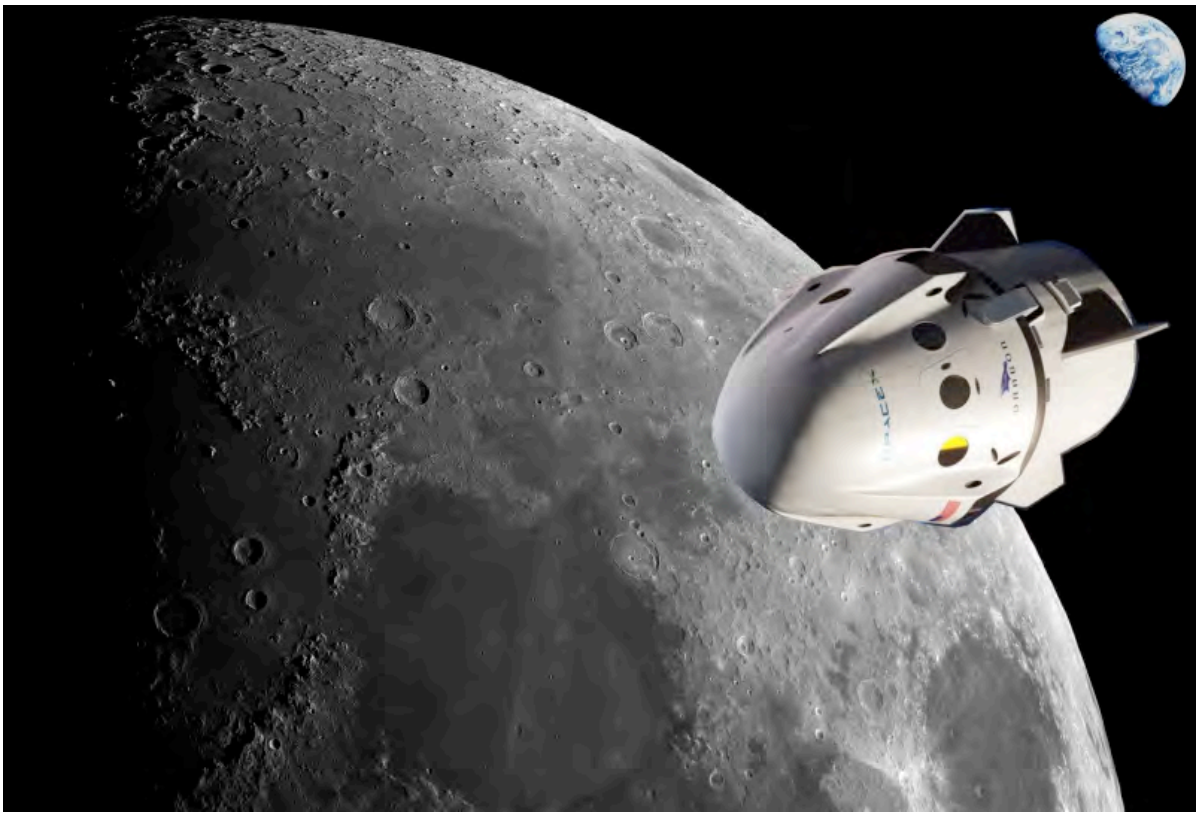

Fig 2. Spacecraft for the circum-lunar space tourism mission, carrying 2 lunar tourists, as proposed by SpaceX.

Credit: SpaceX

Dick Gordon, who has already been there, offers encouragement (Fig 3), if any were needed.

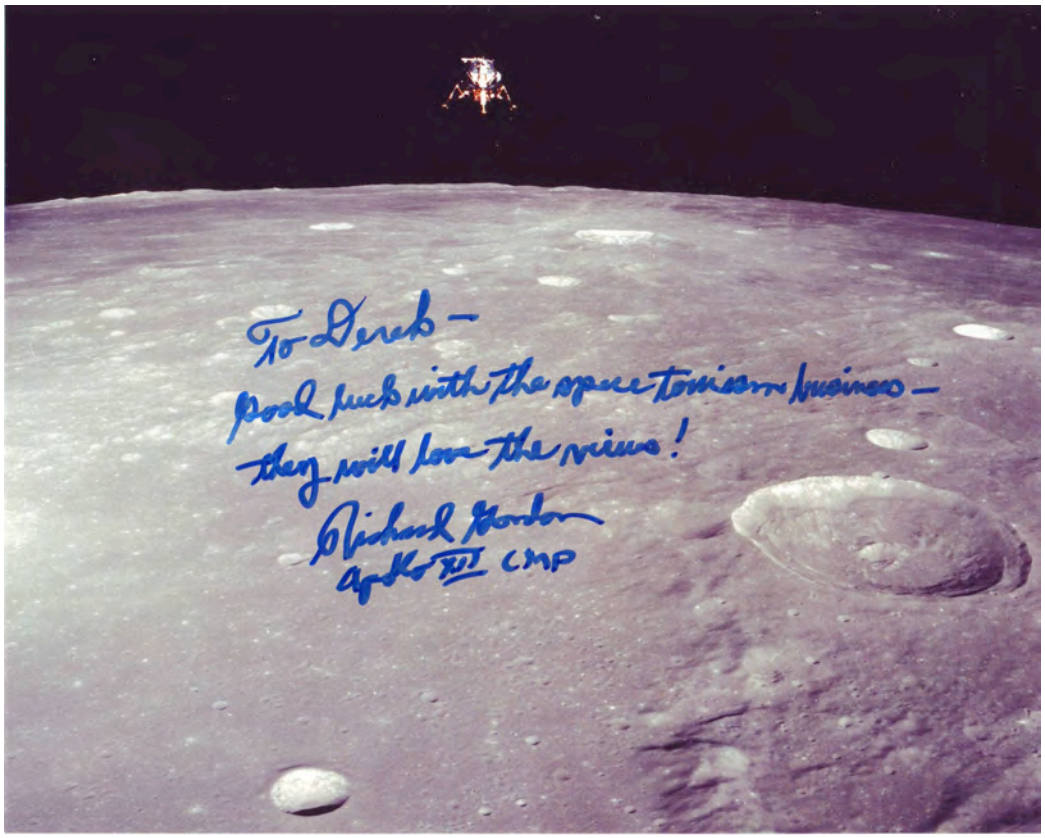

Fig 3. Apollo 12 Command Module Pilot Dick Gordon offers encouragement to future lunar space tourists.

Credit: Author

Space tourism has already had a major role in making space accessible on a regular, reliable and relatively low cost basis, because the potential large pool of space tourists, with their known high elasticity of demand, provides the payloads needed to make reusability worthwhile. And both Blue Origin and SpaceX have now demonstrated that re-usability is here to stay. So, it is now only a matter of time before we start to have private commercial payloads landing on the Moon, some robotic, and eventually some with crews and passengers.

And this brings up important questions. There has been a paradigm shift from government-provided space exploration to the new commercial enterprises. Who is now responsible, if anyone, for all this potential new activity on the Moon, and are there any rules that must be followed? Who issues Drivers' Licenses, presumably international, for rovers on the Moon, and what are the "Rules of the Road", if any, which must be followed?

3. PROTECTING ARTIFACTS – THE LEGAL SITUATION

The short answers to the questions posed are that (1) there is indeed *no* single appointed entity, whether national or international, and (2) there are *no* internationally agreed *"*Rules of the Road" that must be followed. This omission has been pointed out for some time (eg Ref 4, 2009). There is, however a regulatory background which must be understood.

No *country* can lay claim to owning any part of the Moon as territory. This much is clear. This is because of the provisions of the Outer Space Treaty of 1967 (whose formal name is "The Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies"). What about a *person or commercial entity* mining on the Moon? That is something that is still being discussed by international lawyers. The Government of Luxembourg certainly thinks it could be OK, and has been setting up a regulatory regime to favor mining on celestial bodies in general. The US government has also put in place some domestic legislation aimed at enabling commercial developments on celestial bodies, via a special provision of the US Commercial Space Launch Competitiveness Act (HR2262) of November 2015. The relevant text is:

"A United States *citizen* engaged in commercial recovery of an asteroid resource or a space resource under this chapter shall be entitled to any asteroid resource or space resource obtained, including to possess, own, transport, use, and sell the asteroid resource or space resource obtained in accordance with applicable law, including the international obligations of the United States".

Could one therefore even mine, in an extreme case, next door to a famous legacy site such as Tranquility Base, which was used by the Apollo 11 crew? At present, it would appear that there might be nothing to stop someone from doing this. The situation regarding ownership and rights for *abandoned artifacts* which are on the surface of the Moon is at least very clear. They still belong to the nation which put them there in the first place.

Let us consider, however, *why* it is necessary to clarify responsibilities and "Rules of the Road" for future governmental or commercial craft landing on the Moon, particularly when they are close to the sites of previous landings. The main reasons are scientific- and engineering-related, because of the need to protect the record of what has happened to artifacts, including footprints and rover tracks, over the course of the nearly 50 years that they have been undisturbed on the lunar surface. The landing sites represent a perfect laboratory for investigating the impact of radiation and other lunar environmental factors such as Moonquakes over an extended period of time, and any disturbance would ruin this rare opportunity. Also, there are cultural and archaeological reasons for protecting the legacy sites as time capsules of life in the 1960's (Ref 4).

4. THE GOOGLE LUNAR XPRIZE and HERITAGE SITE PROTECTION

The first potential threat to these pristine sites came as a consequence of the announcement of the Google Lunar XPRIZE competition (GLXP) (Ref 5), which was set up in September 2007. The main object of the GLXP was to encourage non-governmental teams to attempt to design, build and launch a spacecraft to land on the Moon, travel 500m, then send back High Definition images. Various teams approached the problem in different ways, in attempting to win the $30M prize purse. Some produced designs where a lander deployed a rover which would then in turn travel the distance and send back the images; others used a hopper approach where the lander, instead of deploying a rover, took off from the landing spot and translated over the lunar surface the required distance before landing again and sending back the images. Fig 4 is an example of the rover approach, and Fig 5 shows development testing of a hopper.

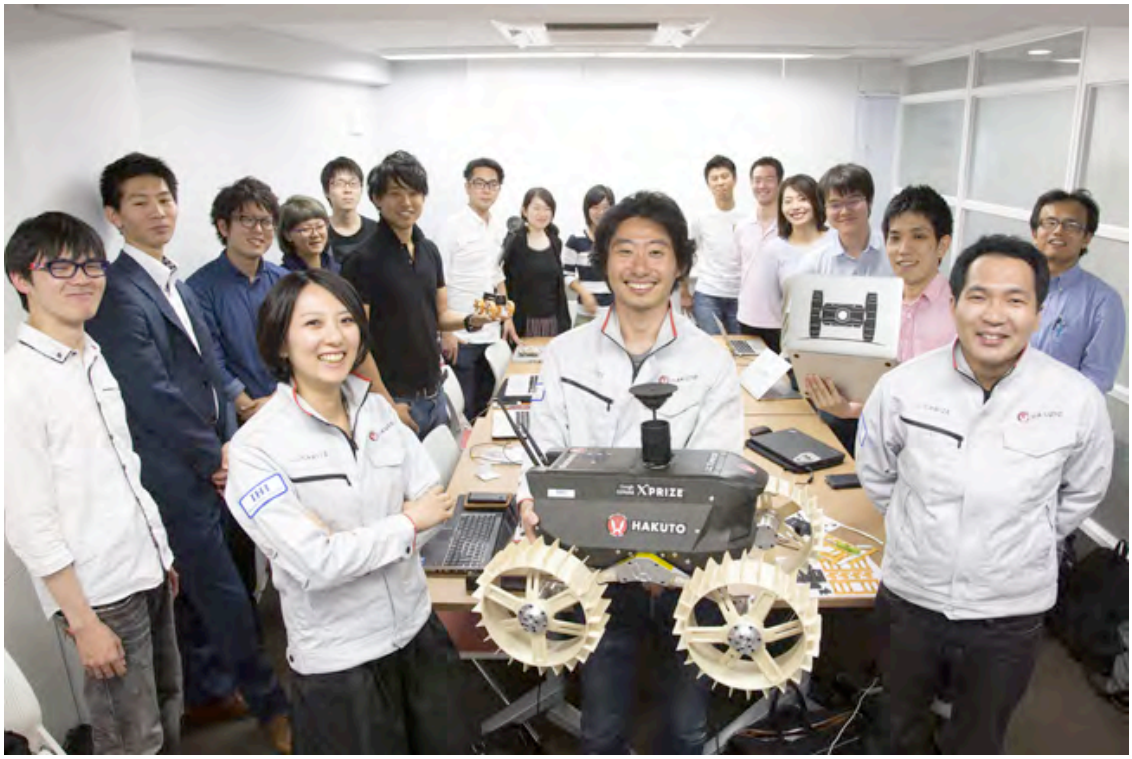

Fig 4 Team members with the development model of the lunar rover proposed by the former GLXP Team Hakuto, Japan.

Credit: Team Hakuto

Fig 5 Demonstration of a lander/hopper (suspended and hovering from test rig) at their KSC test facility, in December 2014, by the former GLXP Team MoonExpress, USA.

Credit: Moon Express

There were also funds set aside in the GLXP competition for so-called Heritage Prizes. Up to $4m extra was made available for any team that landed near a “Heritage Site” and sent back Hi-Def images. So, this was a direct incentive to encourage landers, rovers and/or hoppers to go to sites such as the Apollo landing sites, and this therefore highlighted the concern for some kind of “Rules of the Road” to protect the heritage sites from inadvertent damage.

This concern was recognized, and a joint group of experts from NASA and the National Air and Space Museum (NASM) of the Smithsonian Institution worked together to produce a 93-page guideline document (Ref 6), which while having no legal muscle, either internationally or even within the US, did nevertheless provide some useful suggestions for protecting the sites, while allowing the future explorations to proceed. This 2011 document still today represents the best practice for lunar surface activities. It therefore has provided an initial temporary basis for constructing internationally agreed “Rules of the Road” for moving about and operating on the Moon.

Then, the XPRIZE Foundation in August 2013 put together a panel of 9 volunteer international judges to monitor the competition, and this Judging Panel (JP), of which the author was a member and Vice Chairman, began to consider how they would monitor the conduct of the competition, and whether they had a role in protecting the so-called Heritage Sites.

First of all, the JP studied the July 2011 NASA/NASM Guidelines document, and decided that it was a good basis for proceeding, and that it would not prevent a Team from winning a Heritage Prize if they were to follow the proposed guidelines. The main practical aspect of the guidelines was to establish exclusion boundaries around a given Heritage Site, and ensure that nothing was disturbed within the enclosed zone, whose dimensions varied from site to site based on a number of factors including the site's historic value. *This meant that the judges would be checking that a lander would not land inside the zone, and during the motion phase, no new dust would be thrown up, either by rover wheels, or by hoppers flying overhead, to disturb the pristine surface. Rover speed would need to be limited, and hoppers would have to fly sufficiently high, and tangentially to the exclusion boundaries.* There were different-sized protection zones for each of the heritage sites, and the "most popular" sites, such as that of the Apollo 11 landing, had the most severe proposed restrictions.

In pursuit of achieving these protections, instructions to follow the NASA/NASM guidelines during descent, landing and surface mobility operations, were then written into the GLXP Teams' contract with the XPRIZE Foundation, known as the Lunar Interval Agreement (LIA), in two different places. First of all, in Section XIII, the requirement for achieving the Apollo Heritage Prize was stated thus:

"The Team must submit a plan for what Apollo Site it plans to image, and how the Team plans to capture such imagery or video. Such plan is *subject to prior approval* by the Judging Panel, who will, among other considerations, review the potential impact of the plan according to NASA's "Recommendations to Space-Faring Entities: how to Protect and Preserve the Historic and Scientific Value of US Government Lunar Artifacts"".

Then, some more specific text was added (in Section 3.9) to assist the judges in fulfilling the responsibility for heritage site protection during the Mission Plan Review process:

"The Team must submit the following information to the Judging Panel:

- Description of Heritage Site
- Heritage Site Coordinates
- Artifacts within Heritage Site
- Approach Path
- Descent and Landing Boundary
- Landing Accuracy
- Test and/or simulation data that verifies landing accuracy
- Mobility Path

- Mobility Site Boundary
- Planned linear wheel speed (for rovers)
- Maximum linear wheel speed
- Flyby Path (if hopper)
- Contamination Prevention Protocols, and
- "Heritage Mooncast" (ie broadcast requirements spec) content plan".

(Note that there was a similar set of guidelines for teams targeting non-Apollo Heritage sites).

A set of Judges Guidelines was written in June 2014 (and updated thru to Version 5 in May 2017) to assist the JP in ensuring that any given team was indeed following the initial preliminary "Rules of the Road" for protecting the legacy sites. The teams were given full briefings on the need for Heritage Site Protection, and what they needed to do to achieve this outcome. The author gave a TED Talk (Ref 7) at a conference of GLXP teams in Budapest in June 2014 to underline the need. The teams understood what they must do. The next step of monitoring the competition involved each team developing a Mission Plan which was to be reviewed by the JP, and which explicitly included a section covering the heritage site protections.

The GLXP, with its $30M prize purse provided by Google, had been on offer for almost a decade, and it was therefore decided by the organizers that henceforward, in order to bring the competition to a close, only teams with a launch contract could proceed, and this reduced the field from an original contingent of about 16 to only 5 teams – namely Moon Express, Team Indus, Team Hakuto, SpaceIL, and Synergy Moon. After signing the launch contracts, the remaining teams had just 15 months to complete their missions. The competition would therefore end at midnight on 31st March 2018. These 5 teams worked towards getting their Mission Plans finalized, and reviewed by the Judging Panel, and their spacecraft ready, in the remaining time.

As chance would have it, not one of the 5 teams, that remained in the competition from January 2017 onwards until its end, had declared an intention to land at a Heritage Site. Nevertheless, there were still aspects of heritage site protection which applied even if a landing at a heritage site were not intended. The preliminary "Rules of the Road" guidelines had also indicated the need to protect against *inadvertent* disturbance of the Heritage Sites, eg through accidents during descent, and so there remained work for the JP to do on this topic, in addition to the broader aspects of their due diligence.

Only two teams, Team Indus and Team Hakuto, were able to reach the stage of the competition where they were ready to conduct a full Mission Plan Review, and so the JP visited the Indus facilities in Bangalore, India (Fig 6) in October 2017 for their Review. Hakuto's rover would also be carried to the lunar surface on the same Team Indus lander that transported the Indus rover. The Hakuto rover-specific review took place in Japan after the completion of the Team Indus combined lander and rover Mission Plan Review.

We are therefore able to record some of the specifics of that Bangalore review, as a potentially useful source for future reference.

Fig 6 Team Indus Mission Control, developed and installed in Bangalore, India, for the intended GLXP lunar mission.

Credit: Author

Indus had by this time installed a lunar surface simulator area, which was used for testing rover capabilities including optics, and an operational Mission Control Center. A major concern of JP members was how to be certain that a deployed rover once on the Moon, or a hopper, had indeed traveled the required distance in order to win the Grand prize. There is, after all, no GPS on the Moon. Therefore, much time was spent at the Indus Review in demonstrating rover movement and different ways of measuring the distance traveled, so that a reasonable and agreed error estimate could be derived in advance of the intended launch and landing. And that is what the JP team members were so intently observing in Fig 7, with the results of various distance measurements appearing on the Mission Control displays. Similar tests were later conducted in Japan for Team Hakuto's rover.

Fig 7 The International Judging Panel for the GLXP competition monitors tests during the Mission Plan Review for Team Indus, Bangalore, India, October 2017.

Credit: Author

This having been satisfactorily demonstrated, the JP was then able to study the steps that Indus had taken (on behalf of themselves and Team Hakuto) to ensure that the Heritage Sites would be protected during their mission. They were indeed able to demonstrate:

- Through simulations of descent trajectories, which included a range spread for the approach path, that on landing the nearest Apollo Heritage Site would be no closer than 508km distance, that the nearest non-Apollo Heritage Site would be no closer than 366km distance, and that no overflight of any heritage sites, at any altitude whatever, would take place during approach;
- During the mobility phase there would be no heritage sites within rover range; and
- A Protection Plan was demonstrated with provision for all experiments to be hermetically sealed, and safeguards for the containment of remaining propellant via the use of redundant valves.

As we now know, time ran out before this, or indeed any other, team was able to launch, but the JP had seen the steps that had been taken to protect the Heritage Sites for at least the two teams that were able to conduct Mission Plan Reviews before the JP.

This could be important because it is expected that some of the former GLXP teams intend to continue their efforts to land on the Moon as precursors of commercial delivery missions, and so at least we have seen that the initial protections are workable, provided that there is someone to check for compliance, even if those protections remain totally voluntary.

5. DRIVING ON THE MOON – THE "RULES OF THE ROAD"

So, what can we do to remedy this situation where at present there are only voluntary protection mechanisms? How can we ensure that the Apollo and other historic lunar heritage sites are protected? It could be argued that the Apollo era owes this to all succeeding generations.

The 50-year anniversary of the Apollo 11 landing takes place in 2019, and it is therefore fitting to attempt to protect this legacy through some kind of international agreement – which would also protect the other legacy sites such as the sites and artifacts where the former Soviet *Lunokhod* rover operated. The 2011 NASA/NASM guidelines document, and the GLXP Judging experience, have provided some indications of the way ahead, provided that full international agreement can be achieved. What is needed now is some international agreement about protection zones, operational protocols, and some entity to ensure that these procedures are followed. Such an agreement would make possible the awarding of a "Drivers' License" for any operator of a lunar surface transport who could demonstrate compliance with the agreed international "Rules of the Road".

A start has been made in terms of governmental recognition of the issue by the publication of a US government document (Ref 8) in March 2018. This study report by the President's Office of Science and Technology Policy (OSTP) contains recommendations including the need for various US entities, including NASA, the Department of State, and other interested Departments and Agencies, and with guidance from the National Space Council to:

> "continue discussions regarding lunar heritage site preservation with foreign space agencies, as appropriate";
>
> "with the international community, develop non-binding best practices for preserving and protecting lunar artifacts'; and
>
> "beginning international dialogue on the best ways to mitigate risks presented by future human and robotic exploration to the lunar artifacts"

Furthermore, a new non-profit entity "ForAllMoonkind" (Ref 9) had been set up in November 2017 to attempt to continue the process. In addition to setting up a series of volunteer advisory boards (which include this author) with experts from archeology, law, space engineering, education, etc., its first steps have included:

- Beginning to establish a Registry – a definitive record of all lunar heritage sites and artifacts, using the TODA block-chain protocol;
- Working with The Hague International Space Resources Working Group, which is trying to establish rules for space mining, to ensure that future space mining operations will have to take account of space heritage site protections, by assisting that Group in developing its "Building Blocks" regulatory language;
- Developing a "Do no Harm" Heritage Pledge Declaration, to be agreed and signed by those former GLXP teams who are continuing to pursue their lunar landing attempts; and
- Seeking Observer Status at the UN's Committee on the Peaceful Uses of Outer Space (UNCPUOS) in Vienna, in order to be able to submit language for a potential "International Convention on the Management and Preservation of Universal Heritage in Outer Space".

The group has also been conducting a campaign of public awareness of the issue through advertisements and conference presentations.

6. CONCLUSIONS

Mankind must continue to explore, and space tourism has created the potential markets that make the essential reusable space infrastructure an economic possibility. Lunar space tourism is likely to follow from the Earth-based experiences, in addition to other commercial activities on the lunar surface, many initiated under the auspices of the former Google Lunar XPRIZE competition.

At the 50th anniversary of the Apollo Moon Landings, we note that there are as-yet no agreed international rules in place, nor a responsible oversight authority, to protect the sites and artifacts of the early exploration missions from potential future incursions from commercial explorer spacecraft and potential lunar tourists.

We have seen how the Judging process of the Google Lunar XPRIZE competition had, in the absence of such agreed international rules, put in place a set of protection protocols, relying on initial work that was done by NASA/NASM in developing preliminary guidelines, and how those protocols were proving to be effective, as demonstrated by the Mission Plan Review conducted by Team Indus under the oversight of the panel of independent judges for that competition.

We note that further attempts at heritage site protection are now being made, led by the ForAllMoonkind non-profit group, which is seeking support to rectify the regulatory situation by attempting to get agreement from the international community for an international convention to protect space legacy sites.

While still encouraging the further development of space exploration and even exploitation, we are slowly moving towards protecting the Apollo and other international lunar legacy sites from future incursions. Will the protections be put in place in time before mankind loses this unique opportunity to save the in-situ record of man's first ventures onto another celestial body beyond Earth?

7. ACKNOWLEDGEMENTS

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