THE LEGAL IMPERATIVE TO MITIGATE THE PLUME EFFECT: AN "AGGRAVATION AND FRUSTRATION" THAT IMPERILS OUR HISTORY AND OUR FUTURE

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ABSTRACT

Research indicates that upon approach and landing, lunar lander engine exhaust will blow, rocks, soil and dust at high velocities. This lander ejecta can severely damage hardware even tens of kilometers away from the landing site. Building berms or using terrain obscuration to obstruct or curtail the ejecta each offer only partial solutions to this potentially mission-ending issue because large landers can send ejecta into high trajectories that cannot be successfully blocked. Indeed, it has been shown that it is even possible for ejecta to damage or destroy spacecraft orbiting the Moon. This article maintains that because of these effects, it is necessary to construct landing pads on the Moon to protect all ongoing operations as well as sites of historic significance from destructive ejecta. This article commences by introducing the challenges posed by lunar landing ejecta and summarily describing the detrimental effects on operational hardware and historic sites. The article suggests that obligations and responsibilities as set forth in the Outer Space Treaty and the Liability Convention make the construction of common landing pads a legal, economic and moral imperative. The article further argues that the development and establishment of a common landing pad regime is a vital first step in obtaining the level of international agreement and cooperation that will be needed to assure the successful and sustainable exploration and use of space and its resources.

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I. INTRODUCTION

> There is shadow under this red rock, // (Come in under the shadow of this red rock), // And I will show you something different from either // Your shadow at morning striding behind you // Or your shadow at evening rising to meet you; // I will show you fear in a handful of dust.
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> T.S. Eliot, *The Waste Land*

On April 17, 1967, the United States (US) National Aeronautics and Space Agency's (NASA) Surveyor 3 launched from Cape Canaveral Air Force Station in Florida and began its voyage to the Moon.[1] The Surveyor missions were precursors to the crewed Apollo missions, intended to gather data to assure the feasibility of lunar surface landings.[2] Surveyor 3 landed on the Moon on April 20 and returned more than 6,000 photos to Earth. In addition, the spacecraft confirmed that the Moon's surface was "solid enough to support and Apollo Lunar Module."[3] Surveyor 3 transmitted information for two weeks before making "last contact" on May 4, "two days after the lunar night began."[4] But its contribution to history and space exploration was not over yet.

A little more than two years later, on November 19, 1969, the spacecraft received a visit from the crew of Apollo 12.[5] A "secondary" mission objective of Apollo 12 "was to retrieve portions of the

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[1] Sarah Loff, *Astronauts Pay a Visit to Surveyor 3*, NASA (Apr. 17, 2014), https://www.nasa.gov/content/astronauts-pay-a-visit-to-surveyor-3.

[2] *Id.* In total, there were seven Surveyor missions. Five Surveyor spacecraft successfully soft-landed on the Moon and provided data necessary to support the Apollo missions. *See The Surveyor Program*, LUNAR & PLANETARY INST., https://www.lpi.usra.edu/lunar/missions/surveyor/ (last visited Dec. 17, 2019).

[3] ASIF A. SIDDIQI, BEYOND EARTH: A CHRONICLE OF DEEP SPACE EXPLORATION, 1958-2016 66 (2018).

[4] NASA Science, *Surveyor 3,* SOLAR SYSTEM EXPLORATION, https://solarsystem.nasa.gov/missions/surveyor-3/in-depth/ (last visited Jan. 27, 2020).

[5] Mike Wall, *Happy Anniversary, Apollo 12! 'Pinpoint' Moon Mission Returned Home 50 Years Ago Today,* SPACE.COM (Nov. 24, 2019), https://www.space.com/apollo-12-moon-mission-landing-50-years-ago.html. Apollo 12 was humanity's second crewed mission to the Moon notable for, among other things, its "pinpoint" landing and the deployment by the crew of "the most advanced scientific gear ever carried to another world…" *Id.*

Surveyor 3 spacecraft . . . ."[6] Thus, Apollo 12's Lunar Module, *Intrepid*, purposefully landed just 535 feet away from Surveyor 3.[7] The intent was to obtain parts of the older spacecraft for analysis on Earth in order to examine the effects of long-term exposure to the lunar environment.[8]

The landing was swathed in Moon dust. As the Apollo 12 Mission Report indicates:

> During the final phase of the lunar module descent, the interaction of the descent engine exhaust plume with the lunar surface resulted in the top layer of the lunar soil being eroded away. The particles were picked up by the gas stream and transported as a dust cloud for long distances at high speeds. Crew visibility of the surface and surface features was obscured by the dust cloud.[9]

This "surface obscuration" was not unique to Apollo 12 and indeed, much time has been devoted to understanding the effects lunar dust will have on future missions to and activities on the Moon.[10] An equally worrisome phenomenon was discovered only after the Apollo 12 astronauts returned to Earth with parts of Surveyor 3, including its camera.[11]

Initial terrestrial analysis indicated that Surveyor 3 suffered from sandblasting from the direction of the Lunar Module.[12] In fact, "white craters" were found on the camera.[13] And it was "readily shown that the [Lunar Module] was the most probable origin for

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[6] *The Apollo Program: Apollo 12 (AS-507)*, SMITHSONIAN NAT'L AIR & SPACE MUSEUM, https://airandspace.si.edu/explore-and-learn/topics/apollo/apollo-program/landing-missions/apollo12.cfm.

[7] Mission Evaluation Team, Apollo 12 Mission Report, at ¶ 1.0 (Mar. 1970) [hereinafter Apollo 12 Mission Report].

[8] SMITHSONIAN NAT'L AIR AND SPACE MUSEUM, *supra* note 6.

[9] Apollo 12 Mission Report, *supra* note 8, at ¶ 6.1.

[10] *See e.g.,* Sandra A. Wagner, The Apollo Experience Lessons Learned for Constellation Lunar Dust Management, NASA/TP-2006-213726 (Sept. 2006).

[11] The parts retrieved are listed as "a cable, a painted tube, an unpainted tube, the television camera, and the scoop." Apollo 12 Mission Report, *supra* note 8, at ¶ 3.0.

[12] The initial report indicates "patterns of . . . light- and dark-colored areas [which] can be traced to a lightening mechanism that apparently originated above and behind the camera in the general direction of the [Lunar Module]." R.E. Benson et. al., *13. Preliminary Results from Surveyor 3 Analysis*, *in* Apollo 12 Preliminary Science Report, NASA SP-235, 218 (1970).

[13] *Id.* at 221.

these craters."[14] In short, the preliminary report indicated that the Surveyor spacecraft had suffered significant damage as a result of the Apollo 12 Lunar Module landing – something that took place more than 200 meters away.

In all, more than 36 studies of the Surveyor 3 parts have been conducted by more than 80 investigators.[15] Almost all of the exposed surfaces on the camera retrieved from Surveyor 3 were at least partially covered with a layer of lunar dust.[16] The dust distribution on the hardware indicated that the lunar dust was disturbed and implanted both upon the initial landing of Surveyor 3 and the landing of the Apollo 12 Lunar Module.[17] More significantly, the "Surveyor's surface facing the Apollo [Lunar Module] had been sandblasted thoroughly, with more than 1 cm2 of impacting dust per 1 cm2 of target surface."[18] Dust even reached Surveyor's mirror which, it was determined by examining trajectories, "must have occurred while the [Lunar Module] was about 300 m or more from it landing site."[19] Thus, it was definitively established that the approach of the Lunar Module contributed additional material to the surface of the spacecraft.[20]

In addition to the lunar dust layers on exposed surfaces, the Surveyor 3 camera's exterior surface seemed to be fading and had a series of shadows that did not correspond to solar illumination.[21] An examination of the metal surfaces from the camera provided a direct indication that lunar dust was responsible for a major part of the observed discoloration.[22] Ultimately, the transport of lunar dust induced by landings – which we will refer to as "lunar ejecta" or

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[14] *Id.*

[15] N.L. Nickel & W.F. Carroll, *Summary and Conclusions*, *in* Analysis of Surveyor 3 Material and Photographs Returned by Apollo 12, 9 NASA SP-284 (1972).

[16] *Id.*

[17] *Id.* at 10.

[18] P.T. Metzger et. al., Dust Transport and its Effects Due to Landing Spacecraft (forthcoming presentation at Workshop on the Impact of Lunar Dust on Human Exploration (Feb. 11-13, 2020)) (on file with author).

[19] W.F. Carroll & P.M. Blair, Jr., *Spacecraft Changes, Part A. Lunar Dust and Radiation Darkening of Surveyor 3 Surfaces*, *in* Analysis of Surveyor 3 Material and Photographs Returned by Apollo 12, 28 NASA SP-284 (1972).

[20] *Id.*

[21] *Id.* at 24.

[22] *Id.* at 26.

"plume ejecta" – and the effects of such dust on hardware was concluded to provide significant constraints on future lunar operations.[23] In other words, every time a spacecraft lands on the Moon it has the potential to cause severe damage to any objects already on the Moon – or, as will be shown below, to objects orbit around the Moon.

This article argues that nations engaging in – or whose nationals are engaging in – activities on the Moon have a legal obligation to mitigate the potentially devastating effects of lunar ejecta. It further argues that the most expeditious, beneficial and efficient way to mitigate this risk is to design and construct common landing pads on the Moon using in situ resources. These landing pads should be a product of international collaboration, established in internationally agreed locations that afford requisite access to areas of the Moon significant for further exploration, analysis, or resource development. In support of these arguments, Part II provides an introduction to the challenges posed by lunar landing ejecta and summarily describes the detrimental effects on objects on the Moon including both operational hardware and material of historic significance. Part III reviews legal obligations and responsibilities under general international law as set forth in the Outer Space Treaty, the Liability Convention and other relevant instruments. This Part concludes with the argument that working together to mitigate the potential damage caused by lunar ejecta is a legal, economic and moral imperative. Part IV suggests the best solution is for States and private entities to work together to develop and construct shared lunar landing pads. Ultimately, this article concludes that the establishment of a common landing pad regime is a vital first step in obtaining the level of international agreement and cooperation that will be needed to assure the long-term success and sustainability of all space activity.

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[23] Nickel & Carroll, *supra* note 15, at 20-21.

II. THE PROBLEM: "ONE OF THE MOST AGGRAVATING, RESTRICTING FACETS OF THE LUNAR SURFACE"[24]

A. Lunar Regolith

> One of the surprises of the Apollo experience was how troublesome the lunar dust turned out to be. It obscured their vision on landing, clogged mechanisms, abraded the Extravehicular Mobility Suits (EMS), scratched the instrument covers, degraded the performance of radiators, compromised seals, irritated their eyes and lungs, and generally coated everything with surprising tenacity.[25]

Lunar dust can be characterized as regolith: the "layer of unconsolidated rocks, pebbles, and dust" that exists on the "primordial lunar bedrock." [26] It is estimated that "the entire lunar surface is regolith to a depth of at least several meters."[27] Lunar regolith in particular results from "meteoroid bombardment."[28] As a result, lunar regolith particles are sharp and angular in nature, resulting in a much more abrasive material than their terrestrial counterparts.[29]

Not only is lunar regolith abrasive, it is also adhesive,[30] both mechanically and electrostatically.[31] Mechanical adhesion occurs because of the barbed shapes of the grains of dust.[32] Electrostatic adhesion is caused by the charging of objects by various sources, such as solar wind plasma and photoionization.[33]

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[24] Eugene Cernan, *Apollo 17 Technical Crew Debriefing* 27-27 (Jan. 4, 1973), http://an.rsl.wustl.edu/apollo/data/A17/resources/a17-techdebrief.pdf

[25] James R. Gaier, *The Effects of Lunar Dust on EVA Systems During the Apollo Missions*, NASA/TM-2005-213610 1 (Mar. 2005), https://history.nasa.gov/alsj/TM-2005-213610.pdf.

[26] J. E. Colwell et al., *Lunar Surface: Dust Dynamics and Regolith Mechanics*, 45 REV. OF GEOPHYSICS 1 (2007).

[27] *Id.*

[28] *Id. See also* David McKay et al., *The Lunar Regolith*, *in* THE LUNAR SOURCEBOOK 287, 307 (1991).

[29] Colwell, *supra* note 26, at 4.

[30] *See* Otis R. Walton, *Adhesion of Lunar Dust*, NASA/CR-2007-214685 (Apr. 2007), https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20070020448.pdf.

[31] Timothy J. Subbs et al., *Impact of Dust on Lunar Exploration*, ESA-SP 643 240 (Jan. 2007).

[32] *Id.*

[33] *Id.*

The experience of the Apollo astronauts illustrates the frustrating, and potentially dangerous, effect of the lunar dust on human activity:

> Problems were experienced during Lunar Roving Vehicle (LRV) excursions, with much dust being kicked-up and covering exposed areas . . . leading to increased friction at mechanical surfaces. The resulting abrasive effect of dust increased wear and tear, which significantly limited the lifetime of surface equipment.[34]

Dust coating is a precursor to myriad other problems, which have been sorted into nine main categories by James Gaier. These are: "vision obscuration, false instrument readings, dust coating and contamination, loss of traction, clogging of mechanisms, abrasion, thermal control problems, seal failures, and inhalation and irritation."[35] During Apollo 12, the landing velocity trackers gave false readings when they locked onto moving dust and debris during descent.[36] All environmental sample and gas sample seals failed due to dust, and by "the time they reached Earth the samples were so contaminated as to be worthless."[37] There were reports of equipment being clogged and mechanisms jammed in every Apollo mission.[38]

Apollo 17 commander Gene Cernan remarked that "dust is probably one of our greatest inhibitors to a normal operation on the moon."[39] In his view:

> One of the most aggravating, restricting facets of lunar surface exploration is the dust and its adherence to everything no matter what kind of material, whether it be skin, suit material, metal, no matter what it be and its restrictive friction-like action to everything it gets on . . . For instance . . . By the middle or end of the third EVA, simple things like bag locks and the

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[34] *Id.* Apollo 12 astronauts also observed that regolith was very hard to rub off. Al Bean et al., *Crew Observations*, *in* Apollo 12 Preliminary Science Report, NASA SP-235 36 (1970).

[35] Gaier*, supra* note 25, at 2.

[36] *Id.* at 4.

[37] *Id.* at 6.

[38] *Id.* at 5.

[39] Cernan, *supra* note 24, at 20-12.

> lock which held the pallet on the Rover began not only to malfunction but to not function at all.[40] (internal citations omitted).

B. The Plume Effect

i. Generally

As Gaier notes, "[i]n order for the dust to cause problems, it must be transferred" or transported to the surface in question.[41] This transfer can occur naturally – from, for example, a meteor or micrometeor collision with the lunar surface – or anthropogenically – that is, as a result of human activity.[42] Gaier analyzed three anthropogenic mechanisms: "astronaut walking, rover wheels spinning up dust, and landing and take-off of spacecraft."[43] He determined that "[b]y far the most dust is transported by the landing and take-off of spacecraft."[44]

The interaction of exhaust plumes with loose regolith material was first studied in anticipation of the Apollo crewed lunar landing missions. "NASA investigated the blowing of lunar soil by rocket exhaust plumes in order to ensure safe landings for the Lunar Modules."[45] Of course much was learned after the Apollo landings themselves. The "lack of visible craters under the landed spacecraft . . . [indicates that] a high velocity flow of dust, sand, and possible small gravel moves beneath the standoff shockwave of the plume in a nearly horizontal direction."[46] Put more simply, the rocket exhaust from any lander will blow a significant amount of soil and dust particles in a horizontal sheet along the surface away from the lander, creating significant impacts to the surrounding areas.[47] This expulsion of ejecta is also known as the plume effect, a phenomenon that will occur on Mars as well.[48]

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[40] *Id.* at 27-27, 27-28.

[41] Gaier, *supra* note 25, at 2.

[42] *Id.* The natural mechanisms are not expected to transfer significant amounts of dust as a general matter.

[43] *Id.*

[44] *Id.*

[45] Philip T. Metzger et al., *ISRU Implications for Lunar and Martian Plume Effects*, *in* AM. INST. OF AERONAUTICS & ASTRONAUTICS 4 (Jan. 2009).

[46] *Id.*

[47] *See id.*

[48] *Id.* at 6.

Paul J. van Susante and Philip T. Metzger, writing in the journal *Earth and Space* in 2009, described the effects of space-craft landings:

> During the final moments of lunar landings, the rocket exhaust forms a region of pressurized stagnant gas on the soil beneath the engine nozzle. The gas accelerates horizontally away from the centerline and becomes supersonic, lifting and ejecting an abrasive fine dust spray at upwards of 1000 m/s or faster along with rocks that accelerate to 10 m/s or higher . . . .[49]

After further study, researchers in 2011 determined that particles "can achieve ejection velocities between 300 and 2000 meters per second with the smaller particles generally traveling faster."[50] Building on this work, studies now show that the "finest dust particles can be accelerated up to exit velocity of the rocket propellant, which is 3.1 km/s for the [Lunar Module's] Aerozine/N2O propellants."[51] Since the lunar atmosphere is negligible, "the particles continue at that velocity until striking the lunar surface far away."[52] Indeed, it is hypothesized that some particles will "travel almost all the way around the Moon before impact."[53] Notably, "[l]arger particles generally go slower with sand-size particles travelling 100-1000 m/s, gravel ~30 m/s, and fist-sized cobbles ~10 m/s."[54] No matter where a vehicle lands on the Moon, it will produce ejected particles of varying sizes "that will impact at that distance."[55]

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[49] Paul J. van Susante & Philip T. Metzger, *Design, Test, and Simulation of Lunar and Mars Landing Pad Soil Stabilization Built with In Situ Rock Utilization*, EARTH &SPACE 642, 642 (Apr. 2016) (internal citations omitted).

[50] NASA, *NASA's Recommendations to Space-Faring Entities: How to Protect and Preserve the Historic and Scientific Value of U.S. Government Lunar Artifacts* 12 (Jul. 2011), https://www.nasa.gov/sites/default/files/617743main_NASA-USG_LUNAR_HISTORIC_SITES_RevA-508.pdf [hereinafter NASA Guidelines].

[51] Metzger et al., *supra* note 18.

[52] NASA Guidelines, *supra* note 50, at 12.

[53] *Id.*

[54] Metzger et al., *supra* not 18.

[55] NASA Guidelines, *supra* note 50, at 14.

ii. Consequences

The plume effect results in a number of significant consequences. As an initial matter, the plume ejecta can dangerously obstruct visibility in all directions when a vehicle is landing. Astronaut Pete Conrad reported that when the Lunar Module was at 300 feet, they "picked up a tremendous amount of dust . . . [which] went as far as [Conrad] could see in any direction and completely obliterated craters and anything else."[56] In fact, the dust was so invidious, Conrad could not tell what was underneath the Lunar Module' moreover, he could "obtain absolutely no attitude reference by looking at the horizon . . . ."[57]

The spray of the abrasive and adhesive regolith as a result of the plume effect can also damage the landing vehicle itself, as well as any surrounding hardware on the Moon.[58] For example, as noted in Part I, the surface of Surveyor 3 suffered hundreds of pits, or micro-craters, from the impact of high-velocity lunar particles produced by the landing of the Apollo 12 Lunar Module.[59] The spacecraft had pinholes where sand grains penetrated the paint and cracks that radiated away from the pinholes.[60] Notably, Surveyor 3 was not exposed to the direct spray of the Lunar Module, but instead experienced only the "fringes of the spray" because it was in a crater which kept it below the main spray. [61] Had Surveyor 3 been exposed to the direct spray, "it would have sustained several orders of magnitude greater surface damage, including dust implantation, scouring, pitting, cracking, and microscopic crushing of the surface materials."[62] The damage would also have been far greater if it had been struck by gravel or rocks, rather than smaller dust and soil

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[56] Peter Conrad, *Apollo 12 Technical Crew Debriefing* 9-11 (Dec. 1, 1969), https://www.hq.nasa.gov/alsj/a12/a12tecdbrf.html.

[57] *Id.* at 9-11, 9-12.

[58] Metzger et al., *supra* note 45, at 5.

[59] *See* B. G. Cour-Palais, *Part E. Results of Examination of the Returned Surveyor 3 Samples for Particulate Impacts*, *in* Analysis of Surveyor 3 Material and Photographs Returned by Apollo 12, NASA SP-284 (1972).

[60] *The Science of Plume Effects,* CTR. FOR LUNAR & ASTEROID SURFACE SCI., https://sciences.ucf.edu/class/landing-team/the-science-of-plume-effects/ (last visited Feb. 3, 2020).

[61] Christopher Immer et al., *Apollo 12 Lunar Module Exhaust Plume Impingement on Lunar Surveyor III*, 211 ICARUS 2, 1089, 1101 (Feb. 2011).

[62] NASA Guidelines, *supra* note 50, at 13.

particles.[63] Ultimately, what is clear is the recorded damage to Surveyor 3 "under-represents the degree of damage that could have occurred from [a Lunar Module-sized] vehicle's plume at that distance."[64] And indeed, "[e]xtrapolating to larger landers, simulations show that ejecta velocities increase logarithmically with vehicle mass so a 40 [ton] lander ejects material general 50% faster than a 5 [ton] lander."[65] For frame of reference, the Apollo lunar modules landing mass was five tons. Future landers are estimated to be 20 to 40 tons.[66]

The type of degree of damage forecasted will be catastrophic for functional hardware on the Moon. "The scouring effects of the spray may ruin surface coatings, reflective blankets, and optics, and the injection of dust into mechanical joints may cause increased friction, jamming and mechanical wear."[67] It will also have a devastating impact on objects of historic and cultural significance on the Moon.

The risks extend further than the lunar surface. "The smallest, dust-sized particles achieve near-lunar escape velocity, 2.37 [kilometers per second], and even exceed it by a significant margin, sending them into solar orbit. . . ."[68] Simulations have demonstrated that the ejected material from the Apollo landings was blown into ballistic trajectories that passed through the orbital altitudes of the Apollo command module.[69] This modeling suggests that ejected material can even reach the orbit of – and sandblast—the proposed Lunar Gateway.[70] In short, the potential for damage to the space vehicle itself, surface objects within a very wide radius and orbiting equipment cannot be ignored.

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[63] *Id.*

[64] *Id.*

[65] Metzger et al., *supra* note 18.

[66] *Id.*

[67] Metzger et al., *supra* note 45, at 5. In fact, "[r]ecent experiments blowing simulate lunar soil at spacecraft materials has shown that even at much slower velocities the abrasiveness of the particulates causes unacceptable damage." *Id.* (internal citations omitted).

[68] NASA Guidelines, *supra* note 50, at 13.

[69] Philip T. Metzger et al., *Cratering and Blowing Soil by Rocket Engines During Lunar Landings*, 6th Int'l Conf. on Case Histories in Geotechnical Engineering, Missouri University of Science and Tech. Scholars' Mine, Paper No. 10.01, 8 (2008).

[70] *Id. See also* Robert P. Mueller et al., *Launch and Landing Infrastructure on the Moon*, *in* THE SPACE CONGRESS PROC. (Dec. 2012).

In the upcoming years, there will be an increased level of lunar activity as plans for lunar resource extraction and even human communities on the Moon continue to grow more realistic.[71] These increasingly ambitious plans will require larger and more powerful lunar landers which will blow larger particles – including rocks – at even higher velocities than indicated by the Surveyor 3 studies.[72] In fact, it has even been suggested that aside from the particle ejecta, exhaust gases are

> . . . a phenomenon of concern. The Moon does not possess an atmosphere but rather an exosphere composed of particles that seldom collide. Its total mass is estimated at approximately 25mT but each Apollo mission is estimated to have added nearly 10 mT of gases to the lunar exosphere from engine exhaust alone, raising concerns about the long-lasting effects that vigorous lunar activity might have on the lunar exosphere or the creation of a long-lasting lunar atmosphere. A lunar atmosphere would disrupt scientific objectives and special industrial processes that demand the unique high-vacuum lunar surface environment. (citations omitted)[73]

C. Responses

The plume effect and its associated challenges have not been ignored by scientists. Numerous papers have been written about

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[71] *See* Mike Wall, *50 Years After Apollo 11, A New Moon Rush Is Coming,* SPACE.COM (Jul. 22, 2019), https://www.space.com/moon-exploration-plans-nasa-india-china-and-more.html, Robin McKie, *Everyone's Going Back to the Moon. But Why?,* THE OBSERVER, (Jul. 6, 2019), https://www.theguardian.com/science/2019/jul/06/everyones-going-to-the-moon-again-apollo-11-50th-aniversary.

[72] Tarik Malik, *Boeing Just Sent NASA Its Moon Lander Idea for Artemis Astronauts. Here It Is,* SPACE.COM, (Nov. 6, 2019), https://www.space.com/boeing-human-moon-lander-concept-nasa-artemis.html. According to Metzger, the landing mass of the Apollo Lunar Modules was 5 tons. Current models suggest that the landing mass of the Artemis vehicle will be 40 tons. Thus, where the ejected mass related to the Apollo missions was estimated to be 2.6 tons, ejected mass related to future vehicles could be as much as 470 tons. Philip Metzger, et. al., *Constructing Landing Pads from Lunar Materials,* presented at "What Next for Space Resource Utilisation?" Luxembourg (Oct. 11, 2019).

[73] Jeffrey Montes, et al., *Pad for Humanity: Lunar Space as Critical Shared Infrastructure,* PROC. OF THE 17TH INT'L CONF. ON ENG'G, SCI., CONSTR. & OPERATIONS IN CHALLENGING ENV'TS (forthcoming 2020) (on file with author Hanlon).

the effects of both regolith and the plume effect.[74] Further, the Center for Lunar & Asteroid Surface Science, headed by Dr. Daniel Britt at the University of Central Florida, boasts an entire team devoted to the study of planetary landing plume effects.[75]

Despite continuous scientific study of the plume effect after its discovery in 1972, it was not until 2010 that any formal steps were taken to address the potentially catastrophic effects lunar ejecta could have on objects on the Moon's surface. Even then, the actions taken were only a reaction to a private global competition. In 2007, the XPRIZE Foundation and Google LLC sponsored the GLXP Competition, offering a reward of $30 million USD to the first non-governmental team "to land a craft on the Moon, have it travel 500 metres [sic], and then send back high definition images."[76] The GLXP competition also included at least two "heritage" prizes:

> The $4 million [USD] Apollo Heritage Bonus Prize is for the first team that takes imagery and video of an Apollo site and of a historical artifact associated with the Apollo mission. The $1 million [USD] Heritage Bonus Prize is for the first team that take imagery and video of a historical site of interest including footage of an artifact associated with a previous mission to the Moon other than the Apollo missions.[77]

As former GLXP judge Derek Weber observed, the sites "would certainly be an attractive target for hi-definition imagery. And once lunar surface tourism begins, it would seem highly probable that the lunar legacy sites, Apollo and others, would represent the 'must-see' destinations of a trip to the Moon."[78] Thus, not only would an initial trip to these venerable sites be likely, we must be prepared for repeat visits from tourists.

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[74] *See e.g.* Metzger et al., *supra* note 18, Gaier, *supra* note 25, Collwell, *supra* note 26, Walton, *supra* note 30, Stubbs, et al., *supra* note 31, Metzger et al., *supra* note 45, van Susante, *supra* note 49.

[75] , *Background*, CTR. FOR LUNAR & ASTEROID SURFACE SCI. https://sciences.ucf.edu/class/landing-team/background/ (last visited Jan. 12, 2020).

[76] Derek Webber, *Protecting Our Lunar Legacy,* ROOM SPACE JOURNAL 106 (Mar. 2019), https://www.forallmoonkind.org/wp-content/uploads/2019/05/098_Webber_lunarlegacy_mar19_DES.pdf.

[77] LUCIAN KAY, TECHNOLOGICAL INNOVATION AND PRIZE INCENTIVES: THE GOOGLE LUNAR X PRIZE AND OTHER AEROSPACE COMPETITIONS 78 (2012); *see also* Webber, *supra* note 76, at 106.

[78] Webber, *supra* note 76, at 106.

Even with only a cursory understanding of the destructive potential of the lunar plume effect, it is not difficult to contemplate the damage that these heritage sites would sustain if a spacecraft landed too close. Some of these sites support ongoing scientific experiments.[79] All of them "represent a cultural resource that preserves elements of life on Earth at the beginning of the Space Age."[80] Damage similar to the "sand-blasting" suffered by Surveyor 3 would not only be irreparable, it would be an incomprehensible assault on otherwise pristine records of humanity's first activities on the Moon.

Primarily in response to queries from certain of the GLXP contestants, in 2010 NASA organized a team solely to address questions regarding the protection of historic sites on the Moon.[81] The team developed and released its report, "NASA's Recommendations to Space-Faring Entities: How to Protect and Preserve the Historic and Scientific Value of U.S. Government Lunar Artifacts" (NASA Guidelines), in July 2011. [82]

The NASA Guidelines recommend the implementation of a two kilometer "exclusion radius" around significant lunar heritage sites. Essentially, per the NASA Guidelines, no vehicle should overfly or attempt to land on the Moon within a two-kilometer radius of any so-called United States Government heritage lander, defined to include the Apollo and Surveyor lunar landing sites.[83] To date, the NASA Guidelines are the only directives that attempt to address the destructive potential of the plume effect in a lunar environment that is about to become much busier.

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[79] Elizabeth Howell, *Why is the Apollo Reflector Experiment Still Operating, 50 Years Later?* SPACE.COM (Jul. 11, 2019), https://www.space.com/apollo-retroreflector-experiment-still-going-50-years-later.html. The crews of Apollo 11, 14 and 15 placed special retroreflectors on the lunar surface which are used to measure the distance between the Earth and the Moon. The reflectors do not require any power and continue to operate. *Id.*

[80] Webber, *supra* note 76, at 107.

[81] White House Office of Science and Technology Policy, *Protecting & Preserving Apollo Lunar Program Lunar Landing Sites & Artifacts*, EXEC. OFF. OF THE PRESIDENT 2 (Mar. 2018).

[82] NASA Guidelines, *supra* note 50. The NASA Guidelines were updated in October 2011 to include imagery from the Apollo missions.

[83] *Id.* at 7.

It is not difficult to argue that, as important as they are, the NASA Guidelines remain woefully inadequate. First, they are written assuming a one ton or smaller lander – the size being proposed by the GLXP contestants – hence they require only a two kilometer landing distance which is likely to be far too small to prevent mission-critical damage from the plume effect caused by much larger landers.[84] Second, they pertain only to a set of United States-owned objects which NASA considers to be artifacts;[85] they do not address heritage or operative objects from other nations. Third, they are not intended to be static, indeed, the authors assumed that the Guidelines would be a "living document" that would continue to evolve over time[86] – yet no changes have been made since 2011. Finally, the NASA Guidelines have no legal authority. They are nonbinding technical recommendations that are not enforceable against US entities and certainly do not purport to have any authority over other national space agencies or commercial entities.[87]

Efforts are being made in the US to strengthen the impact of the NASA Guidelines. The One Small Step to Protect Human Heritage in Space Act, which was passed unanimously by the US Senate in July 2019, requires any entity seeking a US license to conduct activity on the Moon to agree to abide by the NASA Guidelines.[88] It

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[84] E-mail from Philip Metzger, Univ. of Cent. Fla., to Authors (Jan. 26, 2020, 16:36 CST) (on file with author Hanlon).

[85] NASA Guidelines, *supra* note 50, at 5. The Guidelines itemize the artifacts as follows:

> A. Apollo lunar surface landing and roving hardware;
> B. Unmanned lunar surface landing sites (e.g., Surveyor sites);
> C. Impact sites (e.g., Ranger, S-IVB, LCROSS, lunar module [LM] ascent stage);
> D. USG experiments left on the lunar surface, tools, equipment, miscellaneous EVA hardware; and
> E. Specific indicators of U.S. human, human-robotic lunar presence, including footprints, rover tracks, etc., although not all anthropogenic indicators are protected as identified in the recommendations.

Id.

[86] *See* Philip Metzger, Protecting Apollo Sites, CTR. FOR LUNAR & ASTEROID SURFACE SCI., https://sciences.ucf.edu/class/landing-team/protecting-the-apollo-sites/ (last visited Jan. 20, 2020); *see* NASA Guidelines, *supra* note 50, at 6.

[87] NASA Guidelines, *supra* note 50, at 6.

[88] The One Small Step to Protect Human Heritage in Space Act, S. 1694, 116th Cong. § 3 (2019). Author Hanlon worked with the office of Senator Gary Peters on the development and language of this legislation.

remains to be seen if it will be enacted into law.[89] Even if it does, this legislation also falls far short of the types of protections that need to be instituted in order to assure that equipment, whether operational or considered an artifact, is protected from the destructive plume effect produced by future lunar landings. The One Small Step Act is a US national law that will have no bearing on non-US entities. While the NASA Guidelines indicate that "NASA has begun engaging in dialogue with [non-US] space agencies,"[90] bilateral arrangements are both inadequate and shortsighted. The plume effect knows no boundaries and the best, perhaps the only, way to manage and mitigate damage is to work multilaterally to develop not just a common understanding, but a common solution. Not only is this the common sense approach, it is one all but dictated by law. The failure by any landing entity to counter the potential damage posed by lunar ejecta will amount to a violation of international law and result in significant liability for the nation responsible. This is a liability that can and should be avoided.

III. THE IMPERATIVES: LEGAL, ECONOMIC AND MORAL

A. International Law

Space activities – like landing on the Moon – are not strictly supervised or otherwise regulated. The treaty regime governing outer space activities, a set of five agreements negotiated in the 1960s and 1970s, are for the most part aspirational. They are founded on three principal themes: a recognition that space must belong to all humankind, a belief that exploration must occur on the basis of freedom and equality and an admonition that space must be used for "peaceful purposes."[91] However, this freedom is not absolute. Accompanying these strictures is the understanding that

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[89] As of this writing, the companion bill, H.R. 3766 is awaiting passage in the House of Representatives. Once the House votes, the bill will be sent to the President for signature whose approval is required before the legislation becomes law. *See The Legislative Process*, U.S. HOUSE OF REPRESENTATIVES, https://www.house.gov/the-house-explained/the-legislative-process (last visited Jan. 13, 2020).

[90] NASA Guidelines, *supra* note 50, at 5.

[91] *See* Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, arts. I, IV, Jan. 27, 1967, 18 U.S.T. 2410, 610 U.N.T.S. 205 [hereinafter Outer Space Treaty].

States conducting activities in space remain responsible for the objects they launch into space, especially if those objects cause harm to others.[92]

Of course, the space law treaties were not negotiated in a vacuum. Space law is "derived from" and can be viewed as a subset of international law.[93] And indeed, the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies[94] (OST) itself is clear that space activities shall be carried on "in accordance with international law."[95] Thus, the concept of responsibility and liability for activities in space is rooted in general international law, pursuant to which "[e]very internationally wrongful act of a State entails the international responsibility of that State."[96] An "internationally wrongful act" occurs when a State breaches "an international obligation."[97] And actions of private individuals or entities can be attributed to the State when the actions should have been subject to the State's exercise of authority.[98] This point is important as the OST, as its full name suggests, governs only the activities of States, and not private entities. Nevertheless, against this backdrop, the OST offers further elucidation of responsibility and liability related specifically to space activities of both States and their nationals.

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[92] *Id.* arts. VI & VII.

[93] Frans von der Dunk, *Liability Versus Responsibility in Space Law: Misconception of Misconstruction?* UNIV. NEB. COLL. OF L. SPACE, CYBER & TELECOM. L. PROGRAM FACULTY PUBS. 363 (1992).

[94] The Outer Space Treaty has been ratified 107 nations, including all current spacefaring nations. As such, this article focuses on the attachment of liability and responsibility as refined by the Treaty rather than simply the application of general international law. *See* Comm. On the peaceful Uses of Outer Space, Legal Subcomm., *Status of International Agreements Relating to Activities in Outer Space as at 1 January 2019,* 58th Sess., U.N. Doc. A/AC.105/C.2/2019/CRP.3 (Apr. 1, 2019).

[95] Outer Space Treaty, *supra* note 91, art. III.

[96] , G.A. Res. 56/83, annex, art. 1, Draft Articles on Responsibility of States for Internationally Wrongful Acts, U.N. Doc. A/RES/56/83/Annex (Jan. 28, 2002) [hereinafter Draft Articles on Responsibility].

[97] *Id.* art. 2.

[98] *Id.* art. 9. *See also* von der Dunk, *supra* note 93, at 364 ("[A] [S]tate can incur responsibility in case of private acts taking place on its territory or being perpetrated by its nations, and amounting to violations of international obligations, *if* the [S]tate could reasonably have prevented such acts." (emphasis in original) (internal citations omitted)).

B. Article VI of the Outer Space Treaty: Responsibility

Article VI of the OST is very clear that State Parties "bear international responsibility for national activities in space, including the moon and other celestial bodies, whether such activities are carried on by governmental agencies or by non-governmental entities . . . ."[99] Bin Cheng points out that this language gives rise to four specific responsibilities that each State Party to the OST assumes. First, "State activities in outer space [must] comply with" the terms and conditions of the OST.[100] Second, the State has a "[d]uty to assure that non-governmental national space activities comply with the Treaty."[101] Third, the State also has a duty "to subject non-governmental space activities to authorization and continuing supervision."[102] Finally, the State assumes direct "responsibility for non-governmental space activities."[103] The emphasis on non-governmental activities is key. A State not only bears responsibility for the

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[99] Draft Articles on Responsibility, *supra* note 96, art VI.

[100] Bin Cheng, *Article VI of the 1967 Space Treaty Revisited: "International Responsibility," "National Activities," and "The Appropriate State"*, 26 J. SPACE L. 7, 13 (1998).

[101] *Id.*

[102] *Id.*

[103] *Id.* at 14. Some scholars, including Laura Montgomery, argue that Article VI does not require the assumption of responsibility by the State for non-governmental activities.

> If Article VI truly meant that all activities had to be overseen, where would oversight stop? Life is full of activities, from brushing one's teeth to playing a musical instrument, which take place now without either federal authorization or continuing federal supervision. Just because those activities take place in outer space does not mean they should suddenly require oversight.

Regulating Space: Innovation, Liberty, and International Obligations Before the H. Comm. on Sci., Space, and Tech., 115th Cong. (2017) (testimony of Laura Montgomery), *available at* https://docs.house.gov/meetings/SY/SY16/20170308/105659/HHRG-115-SY16-Wstate-MontgomeryL-20170308.pdf. (However, this stance openly contradicts the plain language of the OST. Article VI makes it quite clear that all State Parties "bear international responsibility for national activities in outer space . . . whether such activities are carried on by government agencies or by non-governmental agencies." Moreover, Article VI requires unequivocally that "the activities of non-governmental entities in outer space, . . . shall require authorization and continuing supervision by the appropriate State Party to the Treaty." Outer Space Treaty, *supra* note 91, art. VI; *see also* Cheng, *supra* note 100, at 14. Ultimately, Montgomery's argument misses the point as it is in the best interest of each State Party to continue close supervision of their non-governmental national activities because the "international responsibility" that the State party bears in respect of its nationals pursuant to Article VII of the Outer Space Treaty, considered *infra,* can be onerous indeed.

acts of its nationals, it has an obligation to assure their nationals abide by the terms and conditions of the OST and a duty to properly authorize and supervise any activities by private actors that would fall under the OST.

C. Article VII – Launching State Liability

On top of the international responsibility imposed by Article VI, the Outer Space Treaty imposes, pursuant to Article VII, direct liability on each State Party "that launches or procures the launching of an object into outer space . . . and from whose territory or facility an object is launched, is internationally liable for damage to another State Party."[104] Taken in conjunction with Article VI, this provision makes the State Party liable for damages caused by any and every object it, or its nationals, launch into space – including objects that hard- or soft-land on the Moon. Furthermore, the State Party is responsible, and liable, if the object is simply launched from its facility or territory, even if it has no other connection with the space object. This is a broad burden which starkly emphasized the depth of the responsibility the State Parties expect each other to shoulder with respect to activities in space. If a State Party simply permits its territory to be used for launch, it has culpability in respect of the object launched, period.[105]

This burdensome responsibility is reinforced by the Convention on International Liability for Damage Caused by Space Objects[106] (Liability Convention) which states that the "launching State" is liable for damage caused by its space object. Liability is absolute if damage occurs on Earth or to aircraft in flight, but is fault-based if damage occurs elsewhere.[107] The definition of "launching State" parallels the OST and includes the "State which launches or procures the launching of a space object; . . . [and the] State from whose territory or facility a space object is launched."[108]

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[104] Outer Space Treaty, *supra* note 91, art. VII.

[105] Given this provision, whether Article VI imposes a requirement for State Parties to regulate private activities in space conducted by their nationals is a futile inquiry. The State Party will be liable and it is thus in the best interest of the State Party to properly and responsibly authorize and supervise any private national activity in space.

[106] Convention on the International Liability for Damage Caused by Space Objects, Mar. 29, 1972, 24 U.S.T. 2389, 961 U.N.T.S. 187 [hereinafter Liability Convention].

[107] *Id.* arts. II, III.

[108] *Id.* art. I(c).

While the term “space object” is not defined, extrapolating from the plain language of Article VI of the OST, it must mean any object that is launched into outer space.

Article VIII of the OST requires a “registry” to be maintained by each State Party and indicates, as a logical companion to the burden of liability, that the State “shall retain jurisdiction and control over such object while in outer space.”[109] This registration process is further detailed in the Convention on the Registration of Objects Launched into Outer Space.[110] Further underscoring the duty of States with respect to their activities in space, the Registration Convention opens with a preamble that reminds States that they “bear international responsibility for their national activities in outer space.”[111]

In sum, applying both Articles VI and VII of the OST, a State Party is responsible, or could be held responsible, for any damage caused by lunar ejecta created by a spacecraft landing on the Moon if the spacecraft is:

- Its own object.
- An object owned by its national.
- An object constructed by its national.
- An object operated by its national.
- An object carrying its payload.
- An object carrying the payload of its national.
- Any object for which it may be considered a launching State, that is
    - an object that was launched from its territory
    - an object that was launched from its facility
    - an object who launch was procured by it or its national
    - an object that it or its national launched.

In short, the permutations and implications for liability are manifold should a lunar lander cause damage to any *in situ* object.

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[109] Outer Space Treaty, *supra* note 91, art. VIII.

[110] Convention on the Registration of Objects Launched into Outer Space, Jan. 14, 1975, 28 U.S.T. 695, 1023 U.N.T.S. 15 [hereinafter Registration Convention].

[111] *Id.* Preamble. Note that this reiteration uses the term “their national activities” rather than simply “its activities,” which again emphasizes the fact that a State is responsible for its nationals.

D. International Obligations Imposed by the OST

Based on the foregoing discussion, liability clearly attaches under Article VII. However, the OST contains at least three other relevant legal obligations, breach of which could also give rise to liability. These are encapsulated in Article IX, which indicates, in pertinent part, that State Parties . . . shall: 1) "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"; 2) "conduct exploration of them so as to avoid their harmful contamination"; and 3) refrain from activities which "would cause potentially harmful interference with activities of other States."[112] Thus, a State whose equipment is damaged as a result of plume ejecta generated by the landing of another State's spacecraft on the lunar surface potentially has recourse against:

- the entity whose spacecraft caused the damage, whether a State or a private entity;
- the State or States where the private entity or entities claim nationality as part of the international responsibility of that State pursuant to Article VI;
- the State or States where the private entity or entities are nationals for failure to assure that the national activities were carried out in conformity with the OST as required by Article VI;
- the State or States where the private entity or entities are nationals for failure to adequately authorize and supervise that entity as required by Article VI;
- the launching States pursuant to Article VII;
- the State or States where the private entity or entities are nationals for failure to act with due regard to the corresponding interests of all other States; and
- the State or States where the private entity or entities are nationals for failure to avoid the harmful contamination of the Moon.

Liability arises under Article VII of the OST, and under customary international law, wherein it is generally recognized that an illegal act, or the breach of an international obligation will give

[112] Outer Space Treaty, *supra* note 91, art. IX.

rise to a responsibility to repair, or make a reparation.[113] That said, liability is not necessarily absolute. The victim of damage from plume ejecta related to a particular landing will have to show either that the damage occurred as a result of the fault of the accused perpetrator, or that an international legal obligation has been breached.

i. Fault

The Liability Convention imposes liability on a broad swath of potential defendants who may be considered a launching State. However, the term "fault" is not defined in any of the space treaties, nor has their arisen an opportunity for a court to determine its meaning within the scope of space activities. Turning to international law, Joel Dennerley suggests that the "principle obligation on [S]tates with a fault standard is arguably due diligence."[114]

Dennerley explains that "[d]ue diligence is a duty of conduct, not of result, meaning that the obligation incumbent on [S]tates is to use their best efforts to try to prevent damage or harm occurring to other [S]tates."[115] The duty extends to "cover elements under a [S]tate's jurisdiction and control that it has power over or has the capacity to influence."[116] In the context of damage as a result of lunar ejecta, it can be easily argued by the victim State – whether on its own behalf or on behalf of its national – that "best efforts" requires launching States to understand the environment into which their spacecraft are being deployed and to mitigate risks associated with landing on the loose regolith of the lunar surface. As a result, such States would likely be considered at "fault" for the damage caused. It is conceded that this is a theoretical argument and many different approaches may be taken in regard to the understanding of "fault." Nevertheless, the uncertainty in and of itself should be

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[113] Chorzów Factory Case (Ger. v. Pol.), Merits), 1928 P.C.I.J., (Ser. A) No. 17, at 47 (Sept. 13).

[114] Joel A. Dennerley, *State Liability for Space Object Collisions: The Proper Interpretation of 'Fault' for the Purposes of International Space Law,* 20 EUR. J. OF INT'L L. 281, 293 (2018).

[115] *Id.* at 294.

[116] *Id.* (citing Case Concerning Application of the Convention on the Prevention and Punishment of the Crime of Genocide (Bos. & Herz. v. Serb. & Montenegro), Judgment, 2007 I.C.J. Rep. 43, ¶ 430 (Feb. 26)).

enough to make States consider carefully their international obligations in respect of lunar landings.

ii. Due Regard

Article IX of the OST imposes an obligation on States to conduct activities in space, including on the Moon, with "due regard to the corresponding interests of all other States Parties."[117] It is a standard that remains undefined. However, it is also used in the United Nations Convention on the Law of the Sea which states that freedom of the high seas "shall be exercised by all States with due regard for the interests of the other States in their exercise of the freedom of the high seas."[118]An arbitral tribunal considered the meaning of "due regard" in 2015 and determined that:

> the ordinary meaning of "due regard" calls for the [first State] to have such regard for the rights of [the second State] as is called for by the circumstances and by the nature of those rights. *The Tribunal declines to find in this formulation any universal rule of conduct.* The Convention does not impose a uniform obligation to avoid any impairment of [the second State's] rights; nor does it uniformly permit the [first State] to proceed as it wishes, merely noting such rights. *Rather, the extent of the regard required by the Convention will depend upon the nature of the rights held by [the second State], their importance, the extent of the anticipated impairment, the nature and importance of the activities contemplated by the [first State], and the availability of alternative approaches.*[119] (emphasis added)

Under this interpretation, "due regard" requires a balancing test, taking into consideration the rights of the State that have been impinged by the contested activity, the extent of the impairment, the nature and importance of the contested activity, and the availability of alternative approaches. Again, while it is conceded that this balance will produce different outcomes on a case-by-case basis, the uncertainty in and of itself should be enough to make States

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117 Outer Space Treaty, *supra* note 91, art. IX.

118 United Nations Convention on the Law of the Sea art. 87(2), Dec. 10, 1982, 3 U.N.T.S 1833.

119 The Chagos Marine Protected Area Arbitration (Mauritius v. U.K.), Case No. 2011-03, Award, ¶ 519 (Perm. Ct. Arb. 2015).

consider carefully their international obligations in respect of lunar landings.

iii. Harmful Contamination

Article IX of the OST also requires that States conduct their space activities so as to avoid the harmful contamination of the Moon and other celestial bodies.[120] Once again, the treaty declines to define what "harmful contamination" might entail. Relying on the work of the Committee on Space Research Panel on Planetary Protection suggests that contamination presupposes release of organic materials, as the Panel focuses on "possible effects of contamination of planets other than the Earth, and of planetary satellites within the solar system by terrestrial organisms."[121] It can also be argued, however, that "harmful contamination" includes making celestial bodies like the Moon even more inhospitable by creating massive plumes of regolith that could reduce visibility and render instruments inoperable over broad swatches of landscape. Taken to the extreme, if the plume effect does effectively create a "lunar exosphere" or a "long-lasting lunar atmosphere" that changes the "unique high-vacuum lunar surface environment," this could also be considered a harmful contamination.[122]

iv. Harmful Interference

Finally, Article IX of the OST also requires that States "avoid potentially harmful interference with activities of other States" when conducting their own activities. This is essentially a codification of a State's international responsibility to conduct due diligence in respect of its own activity and the activity of its nationals. There can be no question that creating a plume of regolith that physically damages or renders equipment otherwise inoperable is a "harmful interference" with the activity of another State. The duty to avoid this harmful interference includes understanding the environment into which a spacecraft is being deployed, and mitigating risks associated with that deployment and landing.

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120 Outer Space Treaty, *supra* note 91, art. IX.

121 *Panel on Planetary*, COSPAR COMM. ON SPACE RES., *https://cosparhq.cnes.fr/scientific-structure/panels/panel-on-planetary-protection-ppp/* (last visited Jan. 25, 2020).

122 Montes et al., *supra* note 73.

Moreover, Article IX requires that:

> [i]f a State Party to the Treaty has reason to believe that an activity or experiment planned by it or its nationals in outer space, including the Moon and other celestial bodies, would cause potentially harmful interference with activities of other States Parties in the peaceful exploration and use of outer space, including the Moon and other celestial bodies, it *shall* undertake appropriate international consultation before proceeding with any such activity or experiment.[123] (emphasis added).

Given the potentially devastating consequences of the plume effect, it is reasonable to conclude that this language requires any State intending to land a spacecraft on the Moon, Mars or any other geologically similar celestial body to consult with every nation that has a space object on that body.

E. The Economic Imperative

The Liability Convention states that a claim for damages shall initially be presented through diplomatic channels.[124] Claims may also be pursued through "local remedies."[125] However, "a State shall not . . . be entitled to present a claim under [the] Convention in respect of the same damage for which a claim is being pursued in the courts or administrative tribunals or agencies of a launching State."[126] If no settlement is reached within one year "from the date on which the claimant State notifies the launching State" of the claim, "the parties *shall* establish a Claims Commission at the request of either party"[127] (emphasis added). The Claims Commission is to be composed of three members,[128] all of whom, presumably, will require payment. Ultimately, the decision of the Claims Commission "shall be final and binding," but only "if the parties have so agreed."[129] In other words, after one year of negotiations, one State

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[123] Outer Space Treaty, *supra* note 91, art. IX.
[124] Liability Convention, *supra* note 106, art. IX.
[125] *Id.* art. XI (1).
[126] *Id.* art. XI(2).
[127] *Id.* art. XIV.
[128] *Id.* art. XV(1).
[129] *Id.* art. XIX(2).

may compel all the other States involved to form a Claims Commission, whose decision will not necessarily be final and binding. One can easily imagine a scenario in which a State is forced to participate in the Claims Commission but refuses to agree that any decision will be enforceable. The amount of money and workforce hours involved in this process – State personnel, company personnel (if applicable), attorneys, diplomats, arbitrators, support staff, printing services and all other related expenses – is staggering. Not to mention the fact that focus – both financial and intellectual – on the claims process will detract from far more important goals related to space exploration. In short, costs to all parties involved are high, even before a decision about liability or damages is made.

As far as damages go, while the ideal reparation would be restitution to the original status of the damaged space object, if this is not possible, the responsible party should make "payment of a sum corresponding to the value which a restitution in kind would bear."[130] The question is, what is the corresponding value? If an instrument is destroyed or rendered inoperable, restitution must include all costs associated with repair – including the construction and launch of a replacement. Depending on the mission of the damaged object, the State which caused the damage could also be responsible for lost opportunity and lost data.

Additionally, the value of a lunar heritage site like the Apollo 11 landing area is incalculable. What reparation payment would be sufficient for damage to, or the destruction of, Neil Armstrong's footprints, or the bleached American flags planted during each of the Apollo mission, when such damage is likely to be irreparable?

Compounding the questions of liability and reparations is the fact that lunar ejecta may not cause immediately discernable damage to objects that a more distant from the landing site. An object that may be able to maintain functionality in the way of the plume effect once, may suffer cumulative damage over time as more and more landings occur. Engineers can attempt to develop materials that will be more resistant to sandblasting, but this material would

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[130] Chorzów Factory Case (Ger. v. Pol.), Merits), 1928 P.C.I.J., (Ser. A) No. 17, at 47 (Sept. 13) ("Restitution in kind, or, if this is not possible, payment of a sum corresponding to the value which a restitution in kind would bear; the award, if need be, of damages for loss sustained which would not be covered by restitution in kind or payment in place of it – such are the principles which should serve to determine the amount of compensation due for an act contrary to international law.")

likely be heavier and cost more to build – and launch. Who will determine at what point such precautions need to be taken? In short, the costs associated with damage from plume ejecta could become significant quite quickly, or over a span of time. The international community could prevent these losses by investing in a solution in advance – a path that would eliminate, or, at least, reduce, both uncertainty and cost.

F. The Moral Imperative

i. International Cooperation

The OST uses the word "cooperation" no less than seven times – twice in the preamble and five more times in the substantive terms and condition. The purpose of the Treaty, as set forth in its introduction is to "contribute to broad international co-operation" in the belief that "such co-operation will contribute to the development of mutual understanding and to the strengthening of friendly relations between States and peoples."[131] Articles I, III, X and XI each indicate a purpose to "encourage" or "promote" international cooperation.[132] And Article IX admonishes that the concept of due regard, discussed above, "shall be guided by the principle of co-operation."[133]

Recalling that the OST was negotiated at the height of a Cold War that turned "hot" in Vietnam by 1965,[134] it is indeed astonishing that the OST negotiators focused on the concept of international

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[131] Outer Space Treaty, *supra* note 91, Preamble.

[132] *Id,* arts. I, III, X & XI.

[133] *Id.* art. IX.

[134] President Kennedy sent more than 16,000 military advisers to Vietnam in the early 1960s noting, in 1963 that:

> In the final analysis, it is their war. They are the ones who have to win it or lose it. We can help them, we can give them equipment, we can send our men out there as advisers, but they have to win it, the people of Vietnam, against the Communists . . . .But I don't agree with those who say we should withdraw. That would be a great mistake . . . . [The United States] made this effort to defend Europe. Now Europe is quite secure. We also have to participate—we may not like it—in the defense of Asia.

Vietnam, JOHN. F. KENNEDY PRESIDENTIAL LIBR. & MUSEUM, https://www.jfklibrary.org/learn/about-jfk/jfk-in-history/vietnam (last visited Jan. 26, 2020). President Johnson authorized US troops to begin "military offensives" in 1965. *Id.*

cooperation. This remarkable effort demonstrates the deep-seated understanding that outer space is indeed a new frontier – one that will be best and most successfully utilized if States and their nationals work together. It is submitted that working together to reduce the potential of harm from the plume effect is precisely the kind of cooperation the OST and its negotiators desired and anticipated.

ii. Sustainable Exploration

In June 2019, after nearly a decade of discussion, the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS) "formally approved 21 guidelines for long-term sustainability of space."[135] While these guidelines are voluntary, it is noteworthy that the UNCOPUOS reaches agreement by consensus. Thus, while there is no formal voting process, these guidelines were tacitly approved the 95 State members of the Committee.[136] Among the articulated premises for these guidelines is:

> the understanding that outer space should remain an operationally stable and safe environment that is maintained for peaceful purposes and open for exploration, use and international cooperation by current and future generations, in the interest of all countries, irrespective of their degree of economic or scientific development, without discrimination of any kind and with due regard for the principle of equity.[137]

More specifically, the Guideline D.1 makes the following recommendations:

> 1. States and international intergovernmental organizations should promote and support research into and the development of sustainable space technologies, processes and services and

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[135] Jeff Foust, *Long-Awaited Space Sustainability Guidelines Approved by UN Committee*, SPACENEWS (Jun. 28, 2019), https://spacenews.com/long-awaited-space-sustainability-guidelines-approved-by-un-committee/.

[136] *See Members of the Committee on the Peaceful Uses of Outer Space*, U.N.OFF. FOR OUTER SPACE AFF., https://www.unoosa.org/oosa/en/members/index.html (last visited Jan. 26, 2020).

[137] Comm. on the Peaceful Uses of Outer Space, Guidelines for the Long-term Sustainability of Outer Space, ¶ I.5 Activities, A/AC.105/2018/CRP.20 (Jun. 27, 2018) [hereinafter LTS Guidelines].

> other initiatives for the sustainable exploration and use of outer space, including celestial bodies.
>
> . . .
>
> 4. States and international intergovernmental organizations *should consider appropriate safety measures to protect the Earth and the space environment from harmful contamination*, taking advantage of existing measures, practices and guidelines that may apply to those activities, and developing new measures as appropriate.[138] (emphasis added).

Having had the opportunity to study the plume effect, it is undeniable that sustainable exploration of the Moon requires the development of space technologies that would reduce the potential for harm, especially as plume ejecta could actually denigrate the lunar environment to such an extent as to make it impossible to conduct any useful operations.

iii. Cultural Heritage

Finally, it is submitted that the international community must work together to protect humanity's cultural heritage on the Moon; cooperatively developing ways to mitigate the potential harm of the plume effect would be a significant step towards necessary recognition and preservation. Currently, there are more than 100 historical archaeological sites on the Moon from the crash site of Luna 2 to Apollo 11's Tranquility Base to the tracks of Yutu and Yutu 2.[139] As noted by the non-profit organization For All Moonkind, each of these sites "bears witness to moments that changed, and advanced, our human civilization irrevocably. No longer are we tied to our Mother Earth. In incremental steps, the heavens have been opened for exploration, and celestial bodies for settlement."[140] Indeed,

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[138] *Id.* ¶¶ II.D.1, II.D.4.

[139] *Human Heritage in Outer Space*, FOR ALL MOONKIND, https://www.forallmoonkind.org/moonkind-mission/human-heritage-in-outer-space/ (last visited Jan. 26, 2020). Author Hanlon is the co-founder and President of For All Moonkind, Inc., a not-for-profit organization committed to protecting human heritage in outer space.

[140] *Id.*

> the robots and the astronauts who landed on the Moon were envoys of all humankind, propelled to the heavens on the ingenuity and perseverance of thousands of scientists, engineers, tool workers and dreamers from around the globe. The sites where they sit today are evidence of humanity's first tentative steps off our planet Earth. They mark an achievement unparalleled in human history, and one that is common to all humankind.[141]

Yet these sites and the objects they host enjoy no special stature under space law or international law. Article VIII of the OST is clear that objects in space remain under the jurisdiction, ownership and control of the State that was responsible for putting them there.[142] But the Treaty offers no further protection. While other States will be responsible for any damage done to such objects, two questions are immediately apparent. First, what kind of damage can be claimed to have occurred in respect of an object that is non-operational? Second, even if damage is recognized as having occurred, how would the value or extent of this damage be quantified? If a State, or its national, creates plume ejecta that damages the Apollo 11 Lunar Module, what would restitution look like? From a historical perspective, the Lunar Module is a priceless artifact; from a hardnosed practical or business perspective, however, it is simply a piece of outdated equipment with no current function. The OST is utterly silent with respect to features on these historic sites, like Neil Armstrong's bootprints, the first ever human steps taken on another celestial body. What is the cost if these sites are damaged or destroyed by lunar ejecta? Will their value be calculated based on their historical significance, or simply their objective economic cost? Here on Earth, the preservation of cultural heritage is identified as a fundamental human right; "damage to cultural heritage of any people constitutes damage to the cultural heritage of humanity as a whole."[143] Does the mere fact of being in outer space disqualify and object from being considered heritage?

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[141] *Id.*

[142] Outer Space Treaty*, supra* note 91, art. VIII.

[143] Resolution Adopted by the Human Rights Council on 30 September 2016, A/HRC/RES/33/20*, Preamble. *See also* Delhi Declaration on Heritage and Democracy, International Council on Monuments and Sites (Dec. 11-15, 2017), Preamble.

There are a number of difficult and complex legal issues which arise in respect of heritage in outer space, not the least of which results in a clash of sovereignty and the nonappropriation principle found in Article II of the OST.[144] On Earth, sites which are considered to be "of outstanding universal value from the historical, aesthetic, ethnological or anthropological point of view"[145] can be recognized and protected by the international community. However, a site can only be nominated by the State in whose territory it is found.[146] This model will not work on the Moon as "space, including the Moon and other celestial bodies, is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means."[147]

The nonprofit, nongovernmental organization, For All Moonkind, which is also a Permanent Observer to the UNCOPUOS, has built a diverse team of space lawyers and preservation lawyers who are working together on a volunteer basis to offer solutions that will address these legal issues.[148] In the meantime, the international community can, and should, immediately take steps to protect these sites by collaborating on efforts to mitigate the potential for damage from the plume effect.

IV. THE SOLUTION: SHARED LUNAR LANDING PADS

Having demonstrated the legal, economic and moral imperative to mitigate against the hazards of lunar ejecta, the question is how. One solution is to borrow from the NASA Guidelines to institute and enforce safety zones around both operational and heritage sites.[149] But in some cases, the safety perimeter required to assure safety may be extreme. Moreover, safety zones do little to dispel the visual landing hazards also created by the plume effect. It has also been suggested that lunar ejecta could be blocked using berms, fences or similar barriers. However, as Phil Metzger notes, plume

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[144] Outer Space Treaty, *supra* note 91, art. II.

[145] Convention Concerning the Protection of the World Cultural and Natural Heritage art. 1, Nov. 16, 1972, 27 U.S.T. 37, 1037 U.N.T.S. 151.

[146] *Id.* art. 4.

[147] Outer Space Treaty, *supra* note 91, art. II.

[148] *Legal Research and Strategy*, FOR ALL MOONKIND, https://www.forallmoonkind.org/about/legal/ (last visited Jan. 26, 2020).

[149] *See* NASA Guidelines, *supra* note 50.

ejecta are impossible to block with berms because "particles colliding in flight scatter over the barrier. Also, larger particles like rocks loft over the barrier and arc down into the other side, and the berms themselves scatter the particles in lunar vacuum."[150] Metzger and the Center for Lunar & Asteroid Surface Science (CLASS) aver that "full mitigation requires construction of a landing pad."[151] CLASS proposes the construction of landing pads using in situ resources[152] and, indeed, the Center has "prototyped and studied technologies including sintering lunar regolith with microwaves, sunlight, and/or infrared radiation, applications of polymers to regolith, the use of gravel and pavers, lunar concrete, and more."[153] Its work continues.

Landing pads, however, are not enough in and of themselves. In order to most efficiently and effectively mitigate the risks associated with the plume effect, shared lunar landing pads are a necessity. Why build individual landing pads, when the international community can work together to build and share common landing facilities? Shared landing sites have the potential to reduce the effects of regolith spray on both equipment and the environment. The landing sites should be conceived broadly as landing zones, which may include navigation beacons, lighting, accessibility to and from outposts, regular processes to offload equipment and supplies from landers, refueling systems and power stations.[154]

The concept of shared lunar landing pads is neither new nor outlandish as we can look to terrestrial examples for inspiration and guidance. Shared lunar landing pads could, theoretically, operate similarly to airports here on Earth. Airports have long provided a common place for aircrafts to land and take off, safe transport for

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[150] P.T. Metzger & D.T. Britt, Mitigating Lander and Plume Effects with Space Resources, presented to Developing a New Space Economy (2019), https://www.hou.usra.edu/meetings/lunarisru2019/pdf/5055.pdf.

[151] *Id.*

[152] In-situ resource utilization is the practice of turning indigenous materials into critical resources that would otherwise be brought from Earth. *In-Situ Resource Utilisation*, ESA, https://www.esa.int/Science_Exploration/Human_and_Robotic_Exploration/Exploration/In-Situ_Resource_Utilisation (last visited Jan. 26, 2020). This approach would allow for a practical and efficient method of construction on the lunar surface. *Id. See also* John A. Happel, *Indigenous Materials for Lunar Construction*, 46 APPL. MECH. REV. 313 (1993).

[153] ESA, *supra* note 152.

[154] *See* Metzger, *supra* note 45, at 17.

passengers on the ground and efficiency in the transference of freight. Likewise, the lunar landing pads would provide for safe and sustainable scientific expeditions and operations by various States and private entities.

Aircrafts must meet minimum requirements to safely operate in or out of a given airport.[155] To determine whether the requirements are satisfied, there must be an evaluation of the characteristics of both the aircraft and the landing area.[156] Specifically, the comparison of distances for the aircraft and the availability provided at an airport is imperative.[157] Additionally, airports are zoned to protect against the disturbance of adjoining areas.[158] Airport zoning may include physical requirements, such as height, as well as smoke, dust and electrical interference for surrounding areas.[159] In regards to shared lunar landing pads, it would be similarly necessary to zone the landing pads with the conservation and sustainability of the lunar environment in mind. There would also need to be consideration of the nature of the landing area in relation to the capabilities of the desired landing craft. In short, the example of airports provides us with a conceptual model of how lunar landing pads might work. The only difference, albeit a significant one, is the need for international cooperation.

The benefits of collaborating to build shared landing pads are legion. Among other things:

- States – and private entities – can share the cost of development and construction;
- cooperation will obviate questions of territorial appropriation that would arise should one State seek to build a permanent landing pad on the Moon or anywhere in space;
- the use of shared landing pads will greatly reduce the risk of damage to both operational equipment and objects of significance to our human history and heritage;
- shared landing pads will also decrease the risk of potentially significant costs of pursuing and defending against damage claims, not to mention the cost of reparations;

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155 A.B. McMullen, *Airports: Development and Problems*, 9 J. AIR L. 649, 653 (1938).

156 *Id.* at 653-54.

157 *Id.* at 653.

158 Erwin Seago, *The Airport Noise Problem and Airport Zoning*, 28 MD. L. REV. 120, 124 (1968).

159 *Id.* at 130.

 working to develop shared lunar landing pads will also promote standardization of equipment which will not only increase efficiencies, but assure future commonalities in a harsh environment that will afford States and private entities more opportunity to assist each other when needed;

 the development of shared landing pads will provide invaluable practical experience as humans move beyond the Moon to other celestial bodies, including asteroids and Mars, which CLASS has determined also offers landing ejecta challenges.[160]

But perhaps most important, collaborating to develop and construct shared lunar landing pads provides a foundational agreement upon which other agreements can be built.

V. CONCLUSION

From the launch of Sputnik-1, the first human made object to complete an orbit around the Earth, we have understood that space is something different. The international agreement to assure that the realm of space is free for all to explore – and that it remains a realm of peace – feels, in retrospect almost instinctive. Since 1959, State delegates have met as the Committee for the Peaceful Uses of Outer Space specifically, as its name suggests, to preserve that peace. Today, we close 2019, a year in which we commemorated the 60th anniversary of the first human-made object to land on the Moon and the 50th anniversary of the first human to land on the Moon. And we embrace a 2020 in which we are already celebrating the one-year anniversary of humanity's first robotic foray to the far side of the Moon and anticipating many more trips to come. We look to the Moon as a testing ground for deeper exploration. We eagerly seek resources and challenge ourselves to establish a human community – a village – on our nearest celestial neighbor. In this time, the establishment of a common landing pad regime feels instinctive. It is the next logical step to help assure peace and freedom of access. And it is a vital first step in obtaining the level of international agreement and cooperation that will be needed to assure the long-term success and sustainability of all space activity.

It has been said that "what we do in space and how we do it reflects our values and not just our technologies." When Apollo 11

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[160] Metzger, *supra* note 45, at 1.

made its historic landing on the Moon, it left behind a disc containing messages of peace from the leaders of 74 nations. Every single one of those messages held out the hope that this great achievement – reaching the Moon – would signal "hope for better days for all [hu]mankind" (Costa Rica) and become "a glorious milestone along the road of all [hu]mankind towards the achievement of peace, freedom and justice" (Italy). Now 50 years later, it is our turn to make those hopes come true. We must work together to mitigate the plume effect so that we can all succeed in promoting the sustainable exploration of space and make the development of a collaborative human presence on the Moon a milestone to a future where "[hu]mankind will live in a universe in which peace, self-expression, and the chance of dangerous adventure are available to all." (Australia). Because those are the values that we should reflect.[161]

Together we can at least alleviate the fear in a "handful of dust."

[161] *Messages of Peace*, FOR ALL MOONKIND, https://www.forallmoonkind.org/moonkind-mission/messages-of-peace/ (last visited Jan. 27, 2020) (providing transcripts of the Messages of Peace that were left on the Moon by Apollo 11 Astronauts Neil Armstrong and Buzz Aldrin).