Statement of Mr. John Thornton,
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before the

Committee on Science, Space and Technology, Subcommittee on Space
U.S. House of Representatives

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Chairman Babin, Ranking Member Bera, and Members of the Subcommittee: thank you for the opportunity to appear today to discuss our nation's future on the Moon. Incredibly, America has not had access to the lunar surface since the Apollo Program ended in 1972. This has put the nation at a disadvantage in science, exploration, and commercial activities, as other nations like China have landed increasingly ambitious robotic missions to the surface of the Moon. No doubt these developments weigh heavily in the minds of international governments, research institutions, and commercial customers as they decide whom to partner with to achieve their goals in space exploration and commerce.

As we approach the 50th anniversary of the Apollo 11 landing in 2019, it is imperative that we signal to the world that America intends to once again lead on the lunar surface. This is especially important as the world increasingly looks to new lunar frontiers like the Moon's far side and poles. Thankfully, American industry, with the strong technical support and cooperation of NASA, is restoring access to the lunar surface with affordable small robotic landers that provide significant capability for the government and other customers. American industry has taken the initiative to develop these small robotic lander capabilities with the majority of funding coming from non-NASA sources. In the case of our company, Astrobotic, we have stood as a private company for 10-years now, generating actual revenues from our 11-non-NASA deals. We have built a team of world-class partners, including Airbus DS and ULA, who have joined our mission because we have demonstrated a credible approach to building a spacecraft that can deliver for our customers.

Re-establishing American Access to the Moon with Small Landers

Founded in the Rust Belt in 2007, Astrobotic is one such company leading the way to re-establish American access to the Moon with small robotic lander capabilities. Astrobotic is building the *Peregrine Lunar Lander*, a privately developed spacecraft capable of delivering hundreds of kilograms to the Moon. Peregrine will enable robotic access to the Moon for companies, governments, and universities starting in 2019, for the historically low price of $1.2 million per kilogram.

Astrobotic is poised to provide a critical capability to the burgeoning lunar payload delivery market. The Moon offers untold opportunities for resource development, scientific investigation, technology demonstration, and exploration advancement. With Peregrine, Astrobotic offers a reliable, low-cost cargo delivery service that allows organizations around the world to

Figure 1: Astrobotic's Peregrine Lunar Lander

pursue these opportunities. Each Peregrine mission will deliver a diverse collection of payload types on a single flight to the Moon. With this end-to-end delivery service, payload customers are empowered to build their own payloads, and integrate them onto our lander using Astrobotic's standard interfaces. Once Peregrine lands on the Moon, the vehicle provides power and communications bandwidth to our payloads for the operation of their own missions on the surface.

With this approach, companies and governments are no longer required to build their own launch vehicles, landers, or other costly infrastructure to send and operate missions to the Moon, nor are they burdened with complicated bilateral or multilateral international agreements to make a mission possible. Instead, payload customers can buy just the service they need on Peregrine and make their lunar ambitions a reality faster and cheaper than ever before.

Astrobotic's first delivery mission will be a key demonstration of service for our payload customers. Peregrine will fly its first mission as a shared, secondary payload on the Atlas V launch vehicle, but on future missions two Peregrine landers could fly together as a primary payload to make deliveries at multiple lunar locations on a single flight. Astrobotic will launch a delivery mission to the Moon once per year, creating a regular cadence of low cost missions to the Moon for the world's space agencies and companies.

Serving the Market for Small Lander Services to the Moon

To date, Astrobotic has 11 deals in place from companies, governments, and nonprofits for Peregrine's first mission to the Moon. The manifest includes a payload reservation from the Agencia Espacial Mexicana, or AEM, the Mexican Space Agency. AEM will fly the first Latin American payload to the Moon on board Peregrine. They will join 6 other nations represented on our first mission: the United States, Japan, Mexico, the United Kingdom, Chile, Germany, and Hungary. The diverse international nature of Astrobotic's first mission manifest demonstrates a global pent up demand for lunar services. The AEM reservation to deliver a Mexican payload to the Moon is a model Astrobotic believes will be replicated repeatedly by other space agencies around the world. Many space agencies have the capability to build groundbreaking payloads that could advance the state of the art in a variety of fields; they just need a low cost transportation service to deliver them.

Figure 2: Astrobotic's Payload Manifest to fly on the Peregrine Lunar Lander

The current Mission One manifest includes contracts to carry small lunar rovers, marketing and time capsule artifacts, technology demonstrators, and memorial cremains. Astrobotic's most recent payload contract, which was signed with Atlas Space Operations at the 2017 Paris Air Show, will be a laser communications terminal that demonstrates the first optical communications capability on the lunar surface. Payload customers on board our mission will be able to take advantage of this breakthrough gigabit per second bandwidth, which will enable high definition streaming video. Laser communication services on the Moon is emblematic of the new era on the Moon made possible by small lander services like Astrobotic.

In addition to our existing payload deals, Astrobotic has developed a sales pipeline of 115 deals, valued at more than $1 billion. This pipeline exists today even before our first flight to the Moon, and reflects the

rapidly growing interest in the Moon. Our understanding of the Moon and the opportunities it holds for science, exploration, and commerce has changed dramatically since the Apollo landings. For instance, just a few years ago scientists from Japan discovered that the Moon has cave-like structures under the surface called lava tubes with entrances on the lunar surface known as skylights. Astrobotic has customers that plan to send autonomous rovers into these features to determine the suitability of lava tubes for future human habitation. With natural protection from radiation, meteorites, and thermal variance, lava tubes hold great potential as a location for long-term human settlements on the Moon. Rovers that peer inside lava tubes could also carry out scientific measurements of the cave walls that were at one time exposed to solar winds over billions of years. These measurements could lead to new insights in solar history.

Lava tubes are an exciting new destination for activity, and similarly the Moon's far side is also a previously untapped location for exploration and discovery. All of the Apollo missions landed at the "front side" of the Moon, and were never able to take advantage of the "radio quiet zone" of the Moon, which blocks interfering radio waves from Earth. Some Astrobotic customers seek to place the first-ever telescopes in cislunar space, which would allow for observations of deep space with almost no radio interference from Earth.

In addition to landing and operating at new lunar sites, some Astrobotic customers plan to build on the progress of past Apollo experiments. For instance, some plan to place retroreflector mirrors on the lunar surface to further triangulate the distance from the Earth to the Moon, and carry out experiments in relativity physics. Newly placed retroreflectors would compliment the ones left behind by Apollo. Others are looking to deploy seismometers and other geophysical instruments all over the surface to better understand the nature of the Moon as a planetary body, and augment instruments left behind in just a few locations by Apollo. Astrobotic also has payload customers that plan to trail blaze new experiments not previously seen during Apollo, such as the first plant growth experiments on a planetary body. Those experiments would be the first step toward growing food on other planets, and unlike anything done in the 1960s or 70s.

Making Use of Lunar Water Ice

When the Apollo program left the Moon for the final time, we thought the Moon was a dry and barren place. Today our understanding of the Moon is dramatically different, as more recent missions like NASA's LCROSS revealed the Moon to be a source of water ice. Thanks to LCROSS, we now know the Moon's polar cold traps have been collecting water from icy comet impacts for billions of years. In fact, some believe that there are 'Great Lakes' worth of water at the poles of the Moon. Water ice on the Moon holds enormous potential for deep space human exploration.

Currently the physics of the rocket equation makes it cost prohibitive for most public and private activities to take place beyond Earth orbit today. Anywhere between 80-95% of a rocket's mass is spent on just the propellant needed to reach Earth orbit.[1] This fuel problem in space breaks most business cases beyond Earth orbit, and cripples the plans of space agencies around the world. Hydrogen and oxygen are key propellants that can power missions beyond Earth orbit, and they can be extracted from water ice. Based on prior discoveries by spacecraft like LCROSS, significant quantities of water ice have been definitively shown to exist at the Moon's poles.[2] Thus it is possible to extract and utilize the fuel already at the lunar surface rather than ship it from Earth, which is costly.

[1] https://www.nasa.gov/mission_pages/station/expeditions/expedition30/tryanny.html
[2] https://www.space.com/7530-significant-amount-water-Moon.html

Utilizing fuel derived from lunar water ice, rather than shipping it from Earth could dramatically improve the economics of space activity at the Moon and beyond. For instance, one MIT study found the cost of a human mission to Mars could be reduced by as much as 68% if fuel from the Moon were used, rather than terrestrially-based fuel hauled from Earth.[3] All of this water ice exists at the poles of the Moon, which is why there is so much recent international interest in the lunar poles, including from the Chinese. Make no mistake; extracting water ice from the Moon will be a technically challenging endeavor that will require substantial research and development, technology demonstrations, and plain hard work and persistence over many years. Yet the promise of lunar water ice for our future in space is too exciting to ignore, and our customer pipeline shares this view.

With a capable lander like Peregrine, Astrobotic stands ready to serve the growing interest in the lunar poles with low cost lunar transportation. Small lander services like Astrobotic are well suited to begin the first step of landing and operating at the poles, obtaining ground truth of water ice in the Moon's cold traps, and demonstrating initial techniques to harvest water. Landing and successfully operating at these sites will be the first step toward realizing the promise of lunar water ice for deep space exploration.

It is important to recognize now that as space activities evolve, valuable resources at the Moon could be of strategic interest to the United States in just a few year short years, and U.S. commercial companies like Astrobotic will be best positioned to capture this value for the nation. Policymakers would be wise to recognize that our future plans for human exploration and other space activities beyond Earth could be substantially altered or supported by our access to this lunar water ice.

Building World Class Partnerships

Part of what makes Astrobotic's Peregrine Lander a credible and capable program is the world-class partners who have stood with us, and assisted our company as we progress toward flight. Not only are the following partners making irreplaceable contributions toward our mission, their statements of support indicate the maturity of our program and our approach. Several of them are pillars of the space community and do not lend the support of their brand lightly.

NASA has been an outstanding partner through the Lunar CATALYST program, which provides Astrobotic access to some of the best spacecraft engineers and facilities in the world, as part of NASA's effort to encourage the development of U.S. commercial robotic lunar lander capabilities. Astrobotic applauds the leadership of the Advanced Exploration Systems division within the Human Exploration and Operation (HEO) Mission Directorate for instituting and supporting CATALYST over the last three fiscal years. We also applaud NASA HEO's recent Request for Information (RFI) seeking information on the availability of small payloads that could be delivered to the Moon using U.S. commercial lunar cargo transportation service providers, as well as NASA's joint RFI seeking information on Lunar Surface Cargo Transportation Services from the Science Mission Directorate with support from the HEO Mission Directorate and the Space Technology Mission Directorate. Astrobotic believes the deep insights into programs like ours through the multi-year CATALYST experience now enable NASA to move beyond these RFIs, and make use of our services for their agency's goals in the immediate near term.

United Launch Alliance is partnering with Astrobotic to launch Peregrine as a secondary payload on an Atlas V launch in late 2019. ULA has been an excellent partner and the Atlas launch vehicle has a long history of successfully launching lunar missions, including Ranger, Lunar Orbiter, Surveyor, LRO/LCROSS and GRAIL. Astrobotic is proud to launch on a proven American launch vehicle from Cape Canaveral, Florida.

[3] http://news.mit.edu/2015/mars-mission-save-weight-fuel-on-Moon-1015

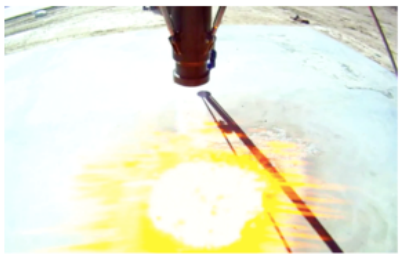
Airbus DS is providing systems engineering support and insight, along with irreplaceable wisdom from past ESA lunar lander experiences. Airbus DS has also provided crucial independent reviews for our spacecraft development milestones.

DHL, the world's largest logistics company, is bringing significant resources to bear for our mission, and is joining our effort as "The Official Logistics Provider to the Moon." Astrobotic's partnership with DHL is another example of the new opportunities that made possible with low cost lunar transportation. No longer is the Moon solely the domain of national governments.

Demonstrating Credibility and Program Maturity

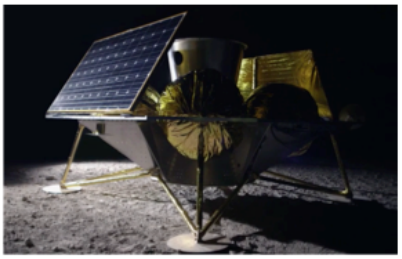
Astrobotic's progress in the lunar delivery market is made possible by the company's steadfast focus on developing a technically credible spacecraft. In fact, the Peregrine Lander recently completed a Preliminary Design Review, with support from Astrobotic's world-class partners, NASA Lunar CATALYST and Airbus DS. Astrobotic has also imported spaceflight talent from across the industry. In the case of our Mission Director, Astrobotic recruited a former 25-year Lockheed Martin veteran, who has put dozens of payloads into space on the Space Shuttle and the International Space Station. Our lead systems engineer is a veteran of 13 space missions including GRAIL, Mars Odyssey, Mars Reconnaissance Orbiter, MAVEN, and Orion. In all, Astrobotic has added more than 90-years of space experience to our team in the last 8-months. Astrobotic has been able to add these space industry veterans because of the reputation we have built over the past decade, delivering results across 23 past and ongoing NASA contracts, and developing actual hardware and technology for our mission.

Across the years we have built and flight qualified a primary spacecraft structure for a Peregrine precursor lander, conducted numerous lunar surface mobility demonstrations at lunar analogue sites, and even demonstrated the world's first visually guided propulsive landing. In the case of our visually guided propulsive landing tests, we flew our Terrain Relative Navigation (TRN) technology three times on a Masten Lander in the Mojave Desert, and successfully demonstrated an autonomous guidance system in a GPS-denied environment that avoided mock ground hazards. TRN is exactly the kind of technology that will be needed to land at challenging environments like the lunar poles.



World's first visually guided propulsive landing

Lander prototype fabrication



Lunar analogue testing with lander & rover prototypes

Delivering NASA Payloads to the Moon

With NASA's deep insight into our program from the multi-year Lunar CATALYST experience, Astrobotic believes now is the right time for NASA to join our payload manifest with a payload reservation. Such a reservation would validate NASA's future use of private payload delivery services, and serve as a key demonstration for the rest of the payload market, which is made up of international space agencies, research institutions, and commercial customers.

We appreciate the leadership of House Commerce-Justice-Science Appropriations Subcommittee Chairman John Culberson (R-TX) and Ranking Member Jose Serrano (D-NY), as well as the members of

the committee for their leadership in providing $30 million in the FY 2018 Appropriations bill for a small robotic Lunar Lander demonstration mission. We are hopeful that the Senate will follow the House's lead and this funding will be included in a final Omnibus. Such funding would allow NASA to join our first mission with its own payload reservation, which would serve as a demonstration of service for the agency.

A NASA payload reservation would be a major step toward bringing small lander capabilities like Peregrine online, and would set up the lunar payload market to flourish. While Astrobotic has secured 11 deals to deliver payload on our first mission, it is no secret that the rest of the international space agency community looks closely to NASA's example for leadership. Such a demonstration of NASA payload delivery would enable the consideration of small landers for space exploration architectures and further help close new business cases in cislunar space.

A NASA demonstration mission would also aid in establishing a regular cadence of small to medium sized payload deliveries, and promote a vital logistics pipeline to the Moon that can be sustainably grown on a diverse market. The self-sustaining small to medium class service can help build the foundation for affordable large-scale lunar endeavors such as human surface missions, which would likely have an exclusive reliance on U.S. Government demand. Small robotic missions are a logical first step toward one day re-establishing a human presence on the lunar surface, and commercial services like Astrobotic exist today with a demonstrated market demand outside of the U.S. Government. The U.S. Government would be wise to ensure that the demand for the small to medium sized payload market is not quashed in a rush to develop larger capabilities that have no outside commercial demand for the foreseeable future.

It should also be noted that Astrobotic and American small lander services are competing with a half-dozen other private lunar payload delivery providers from the international community. A significant payload reservation on board a U.S. commercial provider from NASA would cement our status as the world leader in lunar delivery, and lead to the capture of a substantial portion of the international market by U.S. industry. Our sales pipeline currently has more than 100-deals that could also be won by our international competitors. In the event that one of these competitors captures a major portion of these eligible deals, American payload delivery providers could fall behind, and NASA could be left without a U.S.-domestic lunar payload delivery provider. Assuming that NASA is restricted to using domestic payload delivery providers (as is typically the case for launch vehicles), the agency could be shut out of getting its payloads to the lunar surface, while the rest of the international community is ramping up lunar surface activities. A NASA payload reservation on a small lander service like Peregrine would have a resounding effect toward ensuring American market share in this new lunar market.

Long Term Applications for Small Lander Services

With an imminent demonstration of lunar payload services, small lunar landers like Peregrine can now be leveraged for the purposes of NASA's near term exploration goals. Small robotic landers like Astrobotic's Peregrine stand ready to support upcoming NASA crewed Exploration Missions on SLS-Orion to the Deep Space Gateway by enabling telerobotic access to landers and rovers on the surface. In fact, SLS's unprecedented lift capability could carry multiple Peregrine landers along with crew, allowing access to multiple parts of the Moon during the same mission, while the crew operates from Orion and Deep Space Gateway in orbit. Small robotic lunar landers would be highly complimentary to the Deep Space Gateway. Their use in concert with the Gateway would be the first step toward an eco system of public-private activity around and on the Moon.

In addition to providing direct support to SLS-Orion crewed Exploration Missions at the Deep Space Gateway, there are dozens of small to medium sized NASA payloads that are ready to fly to the Moon on small robotic landers. These payloads run the gamut of science, exploration, and technology

demonstration, and many of them were identified in responses to a recent Request for Information issued by the Advanced Exploration Systems division at NASA in October 2016. As mentioned, it has been more than 40 years since NASA has soft landed payloads on the surface of the Moon. Small lander services have the potential to not just end this drought; they can afford NASA the ability to rapidly follow up an initial experiment with another one.

The value of this capability to science and exploration cannot be overstated. In the past, large sophisticated missions might visit the Moon, make a breakthrough, and then leave the science and exploration communities no ability to practically follow up their groundbreaking findings. Small to medium sized NASA payloads on landers like Peregrine fundamentally speed up the pace of discovery by allowing the agency to return to the Moon rapidly and regularly. The low cost of building and delivering payloads on small landers allows payload builders to experiment and try new approaches they never would have felt comfortable with on a mission that comes around once a decade and costs hundreds of millions of dollars. This rapid cadence of flights opens new horizons in our nation's space capabilities.

From a national policy perspective, small lander private missions to the Moon also provide an opportunity for the United States to help establish international norms for private activities at planetary destinations. For instance, retroreflectors might be carried on board Peregrine for a space agency as a payload to obtain new findings in the Earth-Moon system. At the same time, the permanent placement of these retroreflectors on the lunar surface could serve as physical navigation beacons for aiding and informing future missions to the Moon. Those beacons could also be used to assist in deconflicting interference and establishing keep out zones for future lunar activity in heavily congested areas on the surface. Perhaps most importantly, private small lander missions can establish norms and infrastructure like this retroreflectors example in just a couple of years.

With a commercial market already at hand for lunar payload services, small lander services can quickly ensure America is well represented in a new era of lunar activity, and international norms can be modeled by early American industry actors. In the most immediate term, Astrobotic has been glad to work with the FAA Office of Commercial Space Transportation (AST) to ensure our activities are in compliance with the Outer Space Treaty, and that we are well positioned to receive a mission authorization from the U.S. Government when the time is appropriate. Thanks to the FAA AST, we are confident there are no substantial regulatory barriers to our mission, and our customer base has demonstrated that they feel similarly. Based on our experience with FAA AST to date, we have been impressed with the professionalism, efficiency and responsiveness of their staff in facilitating this process, and commend their efforts to work with industry to enable non-traditional space activities.

NASA Authorization Recommendations

As this committee plans for the next NASA Authorization and conducts ongoing oversight, we urge you to consider authorizing a "Frontier Class Lander Services" program for small robotic landers and rovers to the lunar surface -- similar to the Venture Class Launch Services program for small launch vehicles -- within the NASA Launch Services Program. This would provide a contractual mechanism for NASA and international partners to easily purchase payload space for experiments and technology demonstrators.

Following the Venture Class Launch model would allow all mission directorates at NASA to take advantage of this new American capability. For example, the Human Exploration and Operations Mission Directorate could acquire payload service to the lunar surface for ongoing missions at the Deep Space Gateway. The Science Mission Directorate could opt to deliver science instruments on the Moon, and vastly increase the cadence of flight opportunities in cislunar space. The Space Technology Mission Directorate could increase the Technology Readiness Level of new space technology with actual

experience on the lunar surface. Ultimately a Frontier Class Lander Services program would enhance NASA's portfolio of capability across the agency.

We also encourage NASA to think creatively about how it can help bring international space agency partners to the table to think about opportunities to do science, technology and exploration experiments and missions using this new small lander capability. Many entities in the international space community have expressed a desire to operate missions on the Moon. Perhaps most notably, the head of the European Space Agency, Dr. Jan Woerner, has outlined a vision for a global Lunar Village, in which the next human outpost beyond the International Space Station (ISS) is on the Moon. As a leader of past international cooperative programs like the ISS, NASA would be well suited to aid in the facilitation of placing international space agency payloads on American small lander services.

Conclusion

Mr. Chairman, thank you again for the opportunity today to share our latest developments toward re-establishing American access to the lunar surface. Our team is proud to be leading a Moonshot from America's Rust Belt. We plan to source most of our supply chain from the region, and apply the manufacturing might of our area to reach the Moon. As a company based in Pittsburgh, we know that we stand on the shoulders of giants who helped make our region capable and strong. We also know that these new possibilities on the Moon are made possible thanks to the incredible pioneering spirit of those who came before us.

We now seek to advance these legacies toward a new era in American leadership on the Moon, and we believe this is a special moment in time for our company, our industry, and our country. Both the public and private sectors around the world have outlined plans for lunar activity in the near term. Small lander services to the Moon like Astrobotic now have a verified market demonstrated with real sales, world class partners, and a technically mature spacecraft design. With policy and appropriations support from Congress, American small lander services can capture a significant share of a nascent 21st century space market, while getting NASA back to the Moon. Astrobotic is ready to rise to this occasion, and chart a new course on the lunar surface for American explorers and entrepreneurs.

I would be happy to respond to any questions you or the other Members of the Subcommittee may have.