

Statement of

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Chair Horn, Ranking Member Babin and Members of the Subcommittee, thank you for the opportunity to appear before you today to discuss NASA's deep space human exploration programs, including proposed lunar activities.

In June of 2014 the National Academies of Science, Engineering and Medicine released a report entitled "*Pathways to Exploration: Rationales and Approaches for a U.S. Program of Human Space Exploration*". I co-chaired the committee that produced this report, together with Mitch Daniels, President of Purdue University. The Pathways report was a response to a charge from Congress in the 2010 Authorization Bill, to review NASA Human Spaceflight with a focus on deep space civil missions, and to determine the value and benefits of the program. The key findings of the report were, in summary, the following:

(a) Mars is the horizon goal for human spaceflight, but it is also decades away due to the distance and need for technology development;

(b) A program to send humans to Mars ought to be based on "pathways" which are different options by which to get there, through intermediate stepping stones that provide short term successes, and technology that can feed forward to an eventual Mars mission. The Moon represents one intermediate destination.

(c) Crucial to such a long-range endeavor are international partnerships in which the space agencies of other nations play significant and meaningful roles.

(d) Key technologies that must be developed are (i) entry, descent, and landing (EDL); (ii) advanced in-space propulsion and power, and (iii) radiation safety, among others.

(e) Adopt a strategic approach with what we called "Pathways principles" and decision rules. The decision rules, as detailed in our report, govern how to respond to technical, cost, or schedule issues.

The Moon offers several advantages over a "direct to Mars" approach:

*Proximity:* The Moon is less than five days away, greatly simplifying logistics and response to emergency situations.

*Science:* The Moon provides a superb opportunity to exercise and extend what traditionally have been called robotic "precursor" missions – in this case, to do important lunar science, to prospect for volatiles, to map the surface, to characterize and map subterranean structures such as lava tubes – all of which will generate faster results (than what would be needed at Mars) and hopefully lead to side-by-side exploration with humans.

*Testing:* To establish a more "permanent" rather than "sortie" concept of operations over time as surface systems are developed – this includes continued development of environmental control systems that are more nearly "closed", requiring less provisioning from Earth than does

the ISS. On a less technical front, we have crossed vast seas throughout the history of humanity and learned to live in new lands; the Moon is our cosmic shore and we must learn to live there.

Importantly, our international partners and our commercial partners are better prepared to go forward with us to the Moon and its environs than was the case at the time the Pathways report was published. In that report we were absolutely clear that we cannot “do Mars” without those partners. The Moon represents an opportunity for us to strengthen those relationships, to extend the work done on the ISS and develop a range of technical approaches and capabilities that can only benefit us as we turn our eyes to Mars.

While the Moon is a key steppingstone to Mars, it is important not become so focused on the Moon that investments are made solely for lunar exploration, including some that might not feed forward well to humans on Mars. There are some technologies that will not transfer, but others do: for example, NASA is thinking about the lunar lander system not just in terms of how it would work on the Moon but whether it can be configured there to meet a subset of requirements that would work on both the Moon and Mars—in particular, for ascent. Learning how to mitigate dust infiltration into mechanical, electrical and biological systems is another area where, despite the differences between lunar and Martian dust, mitigation approaches for one may be applicable to the other. The radiation environment on Mars is much less severe for humans than on the Moon, but the Moon provides the hard radiation environment that will allow testing of shielding approaches for the trip to and from Mars. Finally, nuclear technologies – which our Pathways report discussed in terms of nuclear thermal propulsion, will be important on the surface of the Moon, where the lunar night is two weeks long.

What lessons, then, should the human spaceflight program take from the Pathways Report? *First*, we must be in it for the long haul. An Apollo-style sprint to the Moon in and of itself is not a stepping stone to more distant or more permanent goals in deep space exploration. Severe schedule pressures inevitably would lead to laying aside important capabilities that could benefit more ambitious, future endeavors. *Second*, balance schedule against budget. Schedule-driven programs will cost considerably more per year than budget-driven programs—the 2024 goal of putting humans on the Moon should not be undertaken without adequate resources. On the other hand, our report cautions that a budget-driven program can be stretched too thin to save money, until the interval between launches is so long that expertise...and hence safety...cannot be maintained. *Third*, we must engage international and commercial partners in the program, but the US civil space program—NASA— must lead the effort. *Finally*, recognize that IF the nation wishes to undertake a program of deep space exploration—and this must be a long-term national commitment—it must bear in mind that the ultimate payoff, and the horizon goal, is not the Moon but Mars.

In remarks to the University Space Research Association’s 50th anniversary event in April of this year, Scott Pace from the National Space Council talked about sustainability of exploration. One of the points he made was that programmatic sustainability in human exploration requires sustained political support and in turn, sustained political support requires a good cadence of successes. He gave as an example scientific exploration with robotic spacecraft—the long

lineage of remarkable missions from Voyager and Viking to Cassini and Curiosity Rover, from Copernicus to Hubble Space Telescope. It is that steady cadence of successes that enthuses the public and energizes the program for more ambitious missions to come. Taxpayers can see a return on their investment in a short enough time for the relationship between investment and payoff to be clear. And it is precisely that approach which the Pathways report endorsed in order to bring humans outward from a half-century in low Earth orbit to the Moon...and then ultimately to Mars.

As I said in testimony in 2014 on the occasion of the report's release, to reach that horizon goal of Mars will require decades of sustained effort and hundreds of billions of dollars to accomplish. To be sustainable, it will require a steadfast national commitment to a consensus goal, international collaboration, and a budget that increases by more than the rate of inflation.

Our committee was not the first to say that our nation's commitment to human exploration cannot change direction election after election. But in the end our elected leaders are not the impediment to achieving great goals in space, you are the critical enablers of our nation's investment in human spaceflight. Only you can ensure that the leadership, personnel, governance, and resources are in place that will assure human beings will return to the Moon and one day walk on the red soil of Mars.

Thank you again for the opportunity to testify today and I am at your disposal for questions.

Biography: Jonathan I. Lunine is the David C. Duncan Professor in the Physical Sciences and director of the Cornell Center for Astrophysics and Planetary Science. He is interested in how planets form and evolve, how they maintain or lose their ability to host life, and whether life exists elsewhere in our solar system. Lunine is co-investigator on NASA's Juno mission orbiting Jupiter, co-investigator on an instrument for NASA's Europa Clipper mission, and is an interdisciplinary scientist on the James Webb Space Telescope. Lunine is a member of the National Academy of Sciences and has participated in or chaired a number of advisory and strategic planning committees for the Academy and for NASA, including "Pathways to Exploration: Rationales and Approaches for a U.S. Program of Human Space Exploration," which he co-chaired in 2014 with Purdue President Mitch Daniels.