IAC-04-IAA.3.7.1.01

MEDITATIONS ON THE NEW SPACE VISION: THE MOON AS A STEPPING STONE TO MARS

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Abstract

The Vision for Space Exploration invokes activities on the Moon in preparation for exploration of Mars and also directs International Space Station (ISS) research toward the same goal. Lunar missions will emphasize development of capability and concomitant reduction of risk for future exploration of Mars. Earlier papers identified three critical issues related to the so-called NASA Mars Design Reference Mission (MDRM) to be addressed in the lunar context: a) safety, health, and performance of the human crew; b) various modalities of mission operations ranging surface activities to logistics, planning, and navigation; and c) reliability and maintainability of systems in the planetary environment. In simple terms, lunar expeditions build a résumé that demonstrates the ability to design, construct, and operate an enterprise such as the MDRM with an expectation of mission success. We can evolve from Apollo-like missions to ones that resemble the complexity and duration of the MDRM. Investment in lunar resource utilization technologies falls naturally into the Vision. NASA must construct an exit strategy from the Moon in the third decade. With a mandate for continuing exploration, it cannot assume responsibility for long-term operation of lunar assets. Therefore, NASA must enter into a partnership with some other entity – governmental, international, or commercial – that can responsibly carry on lunar development past the exploration phase.

Introduction

In January, 2004, the President of the United States outlined a Vision for Space in a speech at NASA Headquarters. His words laid out a path for exploration of the solar system and set forth quite specific objectives for NASA over the next quarter century.[1]

The Space Shuttle will be returned to flight as quickly as practical, based on the recommendations of the Columbia Accident Investigation Board. Shuttle missions will focus on completing assembly of the ISS, after which the Shuttle will be retired. The functions of the ISS will be directed solely toward support of human exploration beyond low Earth orbit (LEO). A new Crew Exploration Vehicle (CEV) will be developed to carry people to destinations beyond LEO. Cargo transport to the ISS after retirement of the Shuttle will use some other mode.

Most noteworthy in the new Vision for Space Exploration is an emphasis on lunar exploration over the next two decades. The first human lunar expedition is to take place between 2015 and 2020. It will be preceded by a series of robotic missions intended to support future human exploration activities.

The vision statement speaks of exploration across the solar system for scientific purposes and, specifically, searching for evidence of life on the planet Mars. The President asks NASA to conduct human expeditions to Mars, after gathering adequate knowledge about the planet and after successfully demonstrating sustained human exploration missions to the Moon.

This lunar mandate is one of the most debated elements of the Vision for Space Exploration. A central theme to the declaration is the execution of lunar missions and surface activities for the purpose of learning how to successfully carry out human expeditions on Mars. The phrasing of the previous sentence is my own and is the *raison d'etre* for this paper. Just how the Moon will be "used to go to Mars" and why it will be "used to go to Mars" has been the subject of a great deal of misunderstanding and has been misrepresented to bolster the view that the Vision for Space Exploration is unrealistic.

Particularly problematic is a sentence in the President's speech[2]: "Spacecraft assembled and provisioned on the Moon could escape its far lower gravity using far less energy and thus far less cost." While it is true that energy required for a lunar launch is much less than that for a terrestrial launch, elementary systems analysis shows that building a launch complex on the Moon solely for human expeditions to Mars is not practical. I suspect that this statement came from a misunderstanding by the speechwriter and managed to slip through proofreading. Official NASA publication[1] of the elements of the Vision for Space Exploration appearing only a few weeks later do not contain this idea.

Of direct relevance to this paper are two directives related to the Moon: "Undertake lunar exploration activities to enable sustained human and robotic exploration of Mars and more distant destinations in the solar system;" and "Use lunar exploration activities to further science, and to develop and test new approaches, technologies, and systems, including use of lunar and other space resources, to support sustained human space exploration to Mars and other destinations." I will discuss these directives in the context of the historical debates over solar system destinations for human expeditions and in the context of modern views of risk management for space missions.

I note in passing another directive from the Vision for Space Exploration: "Develop and demonstrate power generation, propulsion, life support, and other key capabilities required to support more distant, more capable, and/or longer duration human and robotic exploration of Mars and other destinations." While this objective does not directly mention the Moon, this technology development dovetails with goals of habitation on planetary surfaces and with the utilization of lunar resources.

The Moon versus Mars

I have been studying the Moon as a planetary scientist for NASA since 1963. I first became interested in the concept of a crewed lunar base in 1981. In that year, the Space Shuttle began flying; and the National Space Policy dictated that all other launch vehicles would be phased out. In consulting with NASA/JSC engineers to estimate the potential capability of a scientific unmanned lunar polar orbiter launched from the Shuttle, I discovered that they anticipated the construction of a Space Transportation System consisting of the Shuttle, a LEO space station, and orbital transfer vehicles that could deliver payloads to high orbits routinely. The high orbits could include the Moon.

I and my colleagues became intrigued by the possibility of a lunar base early in the 21st Century at which breakthrough lunar science could be done. NASA was uninterested in studying a future lunar scenario, but over the next few years we built a community of interest, largely external to the Agency.

In the same year, 1981, a group of graduate students at the University of Colorado, frustrated by the lack of closure of the scientific findings from the 1976 Viking mission to Mars, spearheaded a conference to build The Case for Mars. The year 1984 saw the first conference on Lunar Bases and Space Activities of the 21st Century[3] and the second conference on The Case for Mars[4]. Given that both communities saw NASA as carrying out their vision and that the NASA budget was finite, tension inevitably began to develop between the groups.

At the end of the year 1984, both Carl Sagan and Harrison H. Schmitt independently urged the NASA Administrator to commission a review of the state of understanding of human missions to Mars. After a 6-month review, over 100 engineers, scientists, and program analysts prepared working papers. The working group met in June, 1985, to present the papers, which were subsequently published by NASA.[5] This collection remains relevant today in its coverage of the technical and programmatic issues surrounding human expeditions to Mars.

In 1985 at the behest of Congress, the President appointed the National Commission on Space, led by former NASA Administrator Thomas Paine. The Paine Commission, as it was often called, held a number of public hearings and wrote a comprehensive overview[6] of the possibilities of future human activities in space. In my opinion, it is still the most complete and thoughtful look into the future. Unfortunately, the report was scheduled to be delivered to the President just as the Space Shuttle Challenger was lost on launch. The subsequent national mourning and disarray in NASA greatly diminished the potential impact of the report on space policy.

During the stand down of the Space Shuttle in 1986, the NASA Administrator asked astronaut Sally Ride to lead a study to consider a future focus for NASA. In her report[7], *Leadership* *and America's Future in Space*, she identified four possible themes, two of which incorporated large-scale human exploration: Outpost on the Moon and Piloted Missions to Mars. In response the Ride Report, the Administrator chartered an Office of Exploration in NASA Headquarters in 1987 to study possible scenarios of future human exploration.

Two years later, after President George H. W. Bush laid out a vision for the space future in what was initially called the Human Exploration Initiative and later called the Space Exploration Initiative (SEI), NASA prepared a technical response using the results of studies in the Office of Exploration. Although the President's speech and NASA's response prescribed a sequence starting with the Space Station, continuing to "return to the Moon to stay", and then conducting a "journey to Mars", many voices in the space community called for bypassing the Moon to concentrate on human expeditions to Mars.

Their reasoning was not based on engineering considerations. Rather, they characterized the Moon as boring as compared to Mars where the search for life would excite the public. Mars was characterized as more Earthlike and therefore a potential future home for humanity. Although the official strategy called for eventual expeditions to Mars, advocates believed that the space program would "get stuck" on the Moon. In other words, NASA and its aerospace industry clients would create such an investment in lunar missions and facilities that they would find excuses to postpone Mars missions indefinitely. I heard Dan Goldin himself express this point of view in 1998 in answer to a student query on NASA's apparent lack of interest (at that time) in lunar missions.

These arguments ignore dramatic disparities in the technical resources that must be brought to bear to conduct the two programs. One major point of comparison is the amount of mass that must be launched from the Earth to send human missions to Mars or to the Moon. As a rule of thumb, mission planners estimate that 7 tonnes must be launched from the Earth for every tonne returned to Earth from the Moon. For a Mars return, the multiplier is 40. Today, launch costs are so high that launched mass into LEO is often taken as a surrogate for mission cost. By this measure, Mars mission cost is about a factor of six higher than Moon mission cost.

The limited lift capacity of current launch vehicles implies interplanetary spacecraft will be assembled in space from multiple launches. The larger total mass of a human Mars mission requires more launches and results in more complex on-orbit assembly and logistics.

Earth Departure	Year 2014
Out Transit	161 days
Mars Surface Stay	569 days
Return Transit	154 days
4 G Transitions	1G to 0G; 0G to G/3 G/3 to 0g; 0G to 1G
High G Loading	3-5G (TBD) during aerobraking & landing
Crew Size	6

Table 1. Mars Design Reference Mission

A second important characteristic is the frequency of launch windows. Depending on the exact design of the transportation system, lunar launch windows occur at least on monthly intervals. Launch windows to Mars occur only once each 26 months. Should logistics or transportation problems cause a Mars launch to slip, the financial consequences are enormous.

Finally, the missions differ significantly in trip time. Astronauts are in transit for a few days on their way to the Moon. The stay time on the surface is determined by the launch window back to Earth, which in turn is dictated by the mission design. In contrast, the total mission time of the current NASA Mars Design Reference Mission is approximately 30 months. Sometimes it is called the 1000-day mission. The extreme duration of the Mars surface expedition has important implications for risk assessments.

A Matter of Risk

In an attempt to shift the Moon-vs-Mars debate to more quantitative issues, I wrote a paper[8] in 1991, *Lunar Base as a Precursor to Mars Exploration and Settlement*, in which I characterized four areas of major risk should a human expedition to Mars be chosen as the next NASA initiative following ISS. Three of the risk areas were technical, drawn from the 1985 NASA Mars study. The fourth area involved policy (political) risk. Ten years later, beginning in 2001, I revisited each of the technical risk areas in a paper co-authored with a expert in the field.[9,10,11]

The first major risk is the uncertainty in assuring the health and performance of the crew. Physiological, medical, and psychological factors are all important; the latter may be the least understood. The Office of Bioastronautics at the NASA Johnson Space Center maintains a Critical Path Roadmap[12] that formally lists and evaluates the current state of knowledge on specific risk areas within this category.

The second risk category is the lack of experience with mission operations of the scale and scope of a human expedition to Mars. Current experience based on ISS and Space Shuttle has some relevance but does not extend to the mission scenarios envisioned for a crew delivered to the surface of Mars. The Apollo experience is also valuable, but it has largely been lost except for old documentation and memoirs. More detail can be found the paper by Mendell and Griffith.[10]

The next major risk category is reliability and maintainability of the hardware and software systems. The only mission scenario developed in any detail within NASA has a 1000-day duration, including a 500-day stay on Mars. The technological capabilities and the operational experience base required for such a mission do not now exist nor has any self-consistent program plan been proposed to acquire them. In particular, the lack of an abort-to-Earth capability implies that critical mission systems must perform reliably for 3 years or must be maintainable and repairable by the crew.

The fourth risk category identified in my original paper[8] is political viability, an issue currently being debated with regard to the Vision for Space Exploration. If the first space station elements were launched 14 years after program approval, one might ask what interval of apparent inactivity would transpire between approval and launch of the much more challenging piloted mission to Mars. Large-scale publicly funded programs are subject to continuous critical scrutiny by technically unsophisticated observers who want simple answers to simple (and often simplistic) questions. Tangible accomplishments are demanded over time frames determined by political time constants (two to four years in the U.S.).

If an institution wishes to be supported by public funds for a project with a duration of many political time constants, then that institution must be sophisticated enough to plan visible milestones, comprehensible by the public, at intervals appropriate to the funding review process. Historically, NASA has been reasonably successful at maintaining funding of decade-long missions that, however, are understood by all to have a finite duration. After a satellite has been launched and operated for a stated period, it either fails or is shut off. The Congress is not yet comfortable with space programs that are open-ended, such as human exploration of the solar system.

A lunar program of human missions can provide a venue for mitigating all these risk categories. Our experience base easily encompasses Apollo-style landing missions with surface stay times of days. One could design an intelligent program evolution that would grow beyond Apollo scales to MDRM scales and thereby appropriately train and test operations teams, systems concepts, industry design teams, and government management teams in preparation for the interplanetary expeditions.

The counterargument is based on a belief that the risks can be retired or mitigated without an expensive interlude on the Moon. In particular, the lunar environment differs from the martian environment sufficiently that testing hardware on the Moon designed for Mars makes little sense. The major science questions for the two planets also differ. Field investigations to search for evidence of life on Mars are not germane on the Moon. The fluvial landforms, the giant volcanoes, and the polar caps of Mars have no direct geologic counterpart on the Moon.

These counterarguments are cogent as far as they go but neglect a very important reality. No matter what programmatic direction is taken, we will not have enough time or money to do the amount of testing we would like. Therefore, the lives of the Mars crew and the fate of the program will depend ultimately on judgment and experience of engineering and management teams working on the mission. The mission will be safer (i.e., less risky) if those teams have experience working together on problems of a similar kind and of a similar complexity. Complex systems (e.g., a planetary surface habitat or a life support system) will exhibit behaviors and failure modes unlike those predicted by subsystem testing and system integration analysis. Spacecraft engineers know this well. Consumers are more familiar with this phenomenon in computer operating systems. Life support systems, habitation systems, mobility systems, communication systems, power systems, and the human systems will exhibit unanticipated anomalies when combined on the Moon, but these anomalies can be corrected more easily on the Moon than if they were encountered the first time on the surface of Mars. The Moon is the place to learn the art of planetary surface engineering and operations.

Flights to the Moon can be initiated in a significantly shorter time frame than human flights to Mars. Producing a real mission in as short a time as possible is important to mitigation of the political risks described above.

Using the Moon to Go to Mars

From the preceding discussion, we can outline a lunar program as a precursor to piloted Mars expeditions. The principal goal will be risk mitigation at all levels but particularly with respect to human performance, mission operations, and system reliability. All three of these risk categories are driven by the extreme duration of the Mars voyage, the lack of abort-to-Earth options, and the absence of logistical support. Therefore, the ultimate objective of the lunar program is the execution of a mission scenario that demonstrates the ability of design teams, operations teams, management teams, and technology levels to deal robustly with those issues. Such a scenario is a physical facility on the lunar surface at which a crew of at least six lives and works for at least a year out of sight of the Earth, i.e., on the lunar farside.

The lunar farside location is critical to mimic the psychological isolation that will face the Mars explorers. The farside location forces communication via some sort of relay satellite, allowing easy imposition of light-time delays in communications with Mars to strengthen the analogy in operations planning.

Obviously, a lunar outpost is not the first human activity on the Moon. The proximity of the Moon to the Earth allows us to begin the program with short-stay landings. We can sort out the transportation system, lander designs, spacesuit design, and surface environment issues such as dust management and radiation. We can develop the engineering teams to design the more complex systems associated with surface habitation and mobility. At the present time, NASA is internally studying missions landing a crew of four for a duration of about a week as well as missions landing a crew plus a habitat for a stay time of about a month. In my view, this is exactly the correct evolution path to an outpost.

What will a crew do at an outpost? In working on a Mars surface reference mission document, I concluded that the "work time" of a crew will consist of three general areas of activity: (a) scientific investigations, including both field exploration and laboratory analysis; (b) technology development and validation, i.e., learning how to improve and augment the various technical systems; and (c) housekeeping and facility maintenance. Although the details of these activities will differ between the Moon and Mars, the general thrust will be quite similar. For example, a laboratory in a lunar outpost will be equipped with a different instrument complement than would a Mars outpost. On the other hand, basic geological and geophysical analytical tools would be common to both. Philosophy of operations for surface exploration should be similar.

An outpost can also gather information on planetary protection, nuclear power generation, and operation of pressurized surface transport. These issues have been discussed in somewhat more detail in one of the earlier papers.[11]

Science operations on the Moon should be designed to return new scientific knowledge using the lunar location and environment. The "Marslike" quality of the activities comes from their scope and functionality and their impact on mission execution, not from the choice of science objectives. While comparative planetology will interrelate the history of the Moon with the histories of Earth and of Mars, the lunar surface science campaigns will address lunar questions. Where possible, objectives similar to ones to be pursued on Mars should be chosen, e.g., characterization of impact structures, mechanisms of lava emplacement, or search for evidence of biological precursors delivered from external sources.

The Vision for Space Exploration specifically calls for investigations related to lunar resource utilization. Thus, some lunar surface activities will not so directly link to future Mars exploration. In particular, the lunar robotic testbed missions indicated for the second decade of this century will carry some test objectives to determine which resource extractions processes should be developed further. Utilization of resources to enhance or enable surface habitation has priority, but the program should also conduct research into possible commercial applications.

An Exit Strategy for the Moon

I have outlined a rich and challenging human program for the Moon that meets the requirements laid out in the Vision for Space Exploration. However, the discussion so far does not address the concern of many people that a lunar program will be self-perpetuating and human expeditions to Mars will be postponed indefinitely.

When one looks back over the history of NASA, Tom Paine stands out as the last Administrator who believed that NASA was an agency for exploration. When President Nixon rejected the proposal from the Space Task Group[13], he appealed the decision and lost his job. Paine returned years later to chair the National Commission on Space, which issued a visionary report.[6] Under subsequent Administrators, the NASA human spaceflight program concentrated on near-Earth transportation.

The Space Shuttle never became a truly operational vehicle, and NASA was forced to support a standing army devoted to Shuttle flights. The space station program has had a tortuous history with redesigns, delays, and significant budget problems. The combination of Shuttle operations and ISS redirection constantly put pressure on NASA's budget, precluding any substantive studies of future exploration scenarios. NASA made attempts to reduce the demands on its budget using privatization strategies for operations. The Consolidated Shuttle Operations Contract was let, and similar strategies for ISS have been considered.

It takes little imagination to envision the demand for investments in a lunar program preempting preparation for Mars. Let's assume, for argument's sake, that a reformed NASA provides world-class program management and prudent fiscal oversight and that political redirection is minimal during the lunar phase of the Vision for Space Exploration. Even under such ideal conditions, NASA could find its budget squeezed by operating costs of lunar surface facilities.

The human lunar program must incorporate an exit strategy at its initiation. Decisions must be made as to the fate of any habitats, rovers, power stations, or resource extraction plants once the exploration program emphasis shifts away from the Moon. There can be no last-minute, ad hoc decision to "commercialize" the assets.

What is implied here is a partnership, from the beginning, between NASA and another entity or entities. By a partnership, I mean an agreement wherein each partner can specify what requirements to place on the type and scope of investment on the lunar surface. Each partner also assumes financial and/or technical responsibility for certain elements of the program. One can imagine several different scenarios.

Among the most vocal advocates for lunar exploration and development are groups who claim that the private sector can profit from extraction and sale of lunar raw materials or from tourism or from marketing of lunar surface exploration in entertainment venues. Such groups should be given an opportunity to develop credible proposals to accept responsibility for NASA assets at the end of the exploration phase.

Alternatively, a collaboration among space agencies or some other international entity may be interested in taking over the assets. At the present time, at least three other space agencies are preparing or are carrying out lunar missions, and two of them have explicit plans for robotic surface operations.

At the present time, the United States maintains a presence in Antarctica that is managed by National Science Foundation. However, the political motivation for the base is only superficially based on science. By the year 2020, the geopolitical environment may be such that the United States government wants to maintain an official presence on the Moon. If so, the managing agency cannot be NASA, which after transformation will be an agency of exploration and science only.

The policy implications of NASA's exit strategy from the Moon are far reaching and go beyond the mandate of the Agency. A discussion should begin across public policy circles in government and in academia to explore this new avenue.

Conclusions

Lunar missions can be designed and implemented to address critical unknowns associated with a human mission to Mars. Experience gained on the lunar surface is necessary for designers and engineers who will be two generations removed from the last human excursion out of Earth orbit. A lunar program will provide managers a benchmark for assessing the risks of Mars expeditions and will also increase public confidence in the institutions entrusted with the program.

The Vision for Space Exploration represents the kind of strategic decision for the nation that I sought in a paper delivered in 1994 at the International Astronautical Congress[14]. Money spent on this vision is a strategic investment in the national technical base over all. Politicians are not averse to such investments as long as they can see intermediate results within political time frames (i.e., terms of office). In my view, landings on the Moon dramatically make the case that technological progress is being made toward human exploration of the solar system.

Establishment of a permanent presence on the Moon is not a diversion or an impediment but rather part of an historical process. It is a necessary step in understanding human capabilities in space. A lunar program provides an opportunity to build up space capability in an evolutionary and orderly way and to broaden the participation of the public in the excitement of space exploration. Meanwhile, the initial cost of development leading to an interplanetary mission is substantially lower than it would be by proceeding directly to Mars.

Building on the experience of the past, future generations are likely to carry on the tradition of seeing space as a frontier that the human species should probe and conquer without limit. Historically, access to a frontier has generated creativity and changed old ways of thinking in the generation that is raised on its threshold. A well-executed lunar program specifically intended to build experience while returning meaningful science, could easily provide the knowledge and confidence – like Babe Ruth – to point to Mars and hit the ball out of the park.

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