A RATIONALE FOR A HUMAN LUNAR PATHFINDER MISSION

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Abstract

NASA is facing immense challenges. Costs for the International Space Station are climbing into orbit; Mars is far too unknown for human flight; robotic missions seem to fail nearly as often as they succeed; and the shuttle is becoming increasingly obsolete. What is the focus NASA should bring to the new millennium? Clearly NASA must maintain the shuttle and work towards a new launch system. They must complete the International Space Station, especially now that components are in orbit. Robotic exploration of the solar system must continue. But for all practical purposes, this might as well be a path to nowhere. While there are definite long-term payoffs – in the 20+ year timeframe – there is far too much room in the near future for a loss of identity and purpose. Neither the scientific community nor the American public will find much reward in a space program that spends the next five years building a space station, the next ten years visiting it, and in the background launches occasional robotic probes into space, not to be heard from until years later. While these necessary tasks should by all means continue, NASA must place them in the context of a bold vision for the future of spaceflight. This is not a vision consisting of timetables, hypothetical programs and budget projections. Those have been so over-used that they carry no meaning. Instead, this vision must go back to the 1958 Space Act and reiterate why NASA exists; it must create an inspiring image of a future in space where people beyond the agency and its contractors are participants. I believe NASA has the responsibility of opening up the space frontier. Simply investigating LEO does not constitute an opening of the space frontier; this vision must include the moon as a near term destination. There are valid opportunities for commercial enterprise on the moon. NASA must find them and bring them into reality. There are operational procedures and engineering technologies necessary to support lunar operations. We have no idea what they are. NASA must find them and validate them. There are resources in the lunar environment that will enhance our capabilities for missions in other areas of space, both within the Earth-Moon system and further into the solar system. NASA must identify these resources, learn how to tap into them, and create the conditions to make their use a reality. This is why NASA exists. This paper will define and justify the objectives of a pathfinder lunar mission intended to bring focus to some of these issues, and will investigate mission requirements and constraints to be applied to the pathfinder project.

Introduction

The call for a return to the moon has been repeatedly given ever since the final lunar landing. During the period from 1969 to 1972, NASA landed six Apollo missions on the moon, thus fulfilling President Kennedy's pledge to land a man on the moon and return him safely to Earth. These six missions are the only times human beings have left the immediate vicinity of the Earth to travel to another heavenly body. In subsequent years, however, calls to return to the moon have fallen largely on deaf ears. Many times the response has been the question of why. Much of the space program has been criticized for failing to communicate clear rationales for space activity. In a sense, there are a series of three questions that must be resolved. Why should we be in space? Even if we should be in space, why should we go to the moon? If we go to the moon, what should that mission accomplish?

Why are we in space?

Why do we have a space program? Whenever technical difficulties or budgetary problems come to light, this is often the first question out of the mouths of critics. What is there about space that could possibly warrant the expenditures and risks incurred in our endeavors? What are some reasons to enter space? Why should we enter space at all? There are several reasons that come to mind. It is our human destiny (or alternately, it is our human desire/drive). There are commercial opportunities in space. Finally, there is a national mandate to explore space and develop its potential.

Throughout human history, mankind has exhibited a drive to reach beyond the boundaries of the time. Simple curiosity, desires to make new discoveries to improve the quality of life, and a belief that it is simply our purpose have all fueled this drive. Ancient explorers set sail – at tremendous expense and risk – seeking to traverse vast, unknown oceans and explore newly discovered continents. Even today, we still explore these oceans and continents, driven to discover and understand parts of this planet that remain a mystery to us. In the days of American expansion, people believed it was literally God's will – or a Manifest Destiny – for the country to span the continent. This is similar to the beliefs of emperors and kings throughout history who created vast nations. In a sense, space is the perfect "Manifest Destiny." Unlike the more brutal expansions in the world's past, there are no native inhabitants to be oppressed by expansion. Space is vast. No matter how far outward we expand there is still new, unexplored territory.

The National Air and Space Act of 1958 states in Title I, Sec. 102 (c), "The Congress declares that the general welfare of the United States requires that the National Aeronautics and Space Administration (as established by title II of this Act) seek and encourage, to the maximum extent possible, the fullest commercial use of space."[1]

We have only barely begun to fathom commercial possibilities in space. Just fifty years ago, only the shrewdest of visionaries could have even imagined that space could be a potential source of profits. Yet today, the commercial communications industry is dependent on orbiting satellites to provide a communications infrastructure. While commercial profiteering is limited at present to communications in Earth orbit, an unwritten future contains an incalculable domain of business ventures.

A point of inspiration is the city of Las Vegas, and really most of the major cities in the American southwest. Las Vegas is an island of financial profiteering in the middle of the desert. When explorers first reached the area where Vegas now stands, there was nothing but sand. Anyone would have laughed at the idea of creating a major tourist attraction in that location. Yet someone found a way to develop a wildly successful business plan. Hotel and casino operators now have no problem spending incredible amounts of money to develop their facilities, for they know with confidence that they can turn a profit. Space is where Las Vegas was a hundred or two years ago. It is a wilderness, seemingly with very little to offer. But to the proper visionary, it is the source of the next financial empire. Whether through tourism, manufacturing, scientific discovery, or some out her source of income, multitudes of new industries await development.

Finally, in Title I, Sec. 102 (d), the National Air and Space Act imposes the following rationale for American space activity:

> (d) The aeronautical and space activities of the United States shall be conducted so as to contribute materially to one or more of the following objectives:
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> (1) The expansion of human knowledge of the Earth and of phenomena in the atmosphere and space;
> (2) The improvement of the usefulness, performance, speed, safety, and efficiency of aeronautical and space vehicles;
> (3) The development and operation of vehicles capable of carrying instruments, equipment, supplies, and living organisms through space;
> (4) The establishment of long-range studies of the potential benefits to be gained from, the opportunities for, and the problems involved in the utilization of aeronautical and space activities for peaceful and scientific purposes;
> (5) The preservation of the role of the United States as a leader in aeronautical and space science and technology and in the application thereof to the conduct of peaceful activities within and outside the atmosphere;

(6) The making available to agencies directly concerned with national defense of discoveries that have military value or significance, and the furnishing by such agencies, to the civilian agency established to direct and control nonmilitary aeronautical and space activities, of information as to discoveries which have value or significance to that agency;
(7) Cooperation by the United States with other nations and groups of nations in work done pursuant to this Act and in the peaceful application of the results thereof;
(8) The most effective utilization of the scientific and engineering resources of the United States, with close cooperation among all interested agencies of the United States in order to avoid unnecessary duplication of effort, facilities, and equipment; and
(9) The preservation of the United States preeminent position in aeronautics and space through research and technology development related to associated manufacturing processes.[1]

Implicit in this statute are fundamental rationales and the directives to develop and maintain the technological capability to accomplish these rationales. Scientific knowledge, commercial utilization, and American leadership are all directly cited as rationales in the Act. The human drive to explore is not directly mentioned, but is perhaps an indirect motivation for several of the listed objectives.

So now that we have a reason for space activity, what is it that makes the moon an important destination? Is orbiting the Earth truly insufficient? With all the interest in Mars, why not forget about the moon and simply concentrate on terrestrial space stations and Mars exploration?

Why the moon?

Some critics of lunar exploration would ask why go to the moon? They would say that we've been there with Apollo, so there is nothing new to gain. Their logic, however, is flawed. From Salyut to Skylab, to Mir, and now to ISS, we are establishing a human presence in Earth orbit. With each program we are learning new things and accomplishing more than its predecessors. Yes, we have been to the moon before, but only in the most minimal fashion. Simply put, we have not accomplished much of significance on the moon. It is true that the Apollo program provided incredible breakthroughs and discoveries, but only a tiny fraction of what can ultimately be gained from the moon was accomplished through the Apollo program. To say, "why go to the moon since we've been there with Apollo," is comparable to saying, "why build a space station since we've been in orbit with Mercury capsules." Just as Mercury was incapable of performing the missions ISS will accomplish, Apollo was also incapable of conducting the missions a return to the moon would perform. The moon has also been recommended as the next focus for space exploration by numerous committees established to guide space agencies.[2]

The following elements of the National Air and Space Act are perhaps the most directly applicable to the call for a return to the moon:

(3) The development and operation of vehicles capable of carrying instruments, equipment, supplies, and living organisms through space;
(4) The establishment of long-range studies of the potential benefits to be gained from, the opportunities for, and the problems involved in the utilization of aeronautical and space activities for peaceful and scientific purposes;
(5) The preservation of the role of the United States as a leader in aeronautical and space science and technology and in the

application thereof to the conduct of peaceful activities within and outside the atmosphere;

(9) The preservation of the United States preeminent position in aeronautics and space through research and technology development related to associated manufacturing processes.[1]

We currently have no vehicles capable of carrying people to the moon, or any equipment and supplies beyond that of small rovers or science landers. However, only relatively modest developments are required to develop this capability from a synthesis of currently existing space systems. The moon is logically the next developmental step in terms of space transportation capability.

Numerous researchers have proposed benefits from lunar utilization, and establishing studies of those benefits is specifically part of the NASA mission. Another directly relevant section of the National Air and Space Act that also speaks towards this issue is, "The Congress declares that the general welfare of the United States requires that the National Aeronautics and Space Administration (as established by title II of this Act) seek and encourage, to the maximum extent possible, the fullest commercial use of space." This provision does include the moon and is one of the reasons that NASA must return to the moon as quickly as possible.

Just as an arbitrary example on a somewhat trivial level, how many people would pay a couple of hundred dollars for a fist-sized souvenir moon rock? This is one of many hypothetical lunar business opportunities that could be realized in the next few decades. If, perhaps, a business were to develop a viable solar-sail powered cislunar transit system, they might solve the lunar transit problem. The earth/LEO and moon/LLO transportation problems could initially be solved by flying as secondary payloads on other vehicles, assuming some form of lunar activity existed. Once sufficient revenue was generated, the business could perhaps implement its own Earth and lunar launch systems. This is a fairly simplistic commercial use of space that could be conducted while NASA conducts even preliminary lunar exploration.

Numerous other business schemes for lunar revenue are being formulated left and right. Ideas run the gamut from simple banking and commerce using remote servers on the moon to wild, grandiose schemes for mining and construction colonies, lunar fueling stations and even massive lunar hotels – the ultimate Las Vegas of the future. There is, however, one thing all these concepts have in common. They require the development of a capability to travel to the moon and return safely. "The key to unlocking space for business and individuals who will use it to make money, pay taxes, create jobs, and improve the economy is to facilitate the access to space."[3] There is a threshold that leads to entirely new worlds of business opportunities on the moon. We have not yet crossed that threshold. One reason to return to the moon is to take us a step closer. It is NASA's Congressionally mandated responsibility to do all within its power to take us that step closer.

Finally, the United States cannot hope to maintain its leadership role if another nation is the one to implement these studies and develop the associated spacecraft. Simply put, if the Untied States wishes to remain a superpower, this is one of the missions it must conduct.

Still, why not just do Mars?

To a large extent, the preceding information has provided rationale for a return to the moon. But in the context of possible Mars exploration, the issue of Mars must be addressed. Some argue that the rationales for returning to the moon are valid, but they are outweighed by the rationales for Mars exploration. These people see Lunar and Mars programs as competitors, such that we will either do the moon now, or we will do Mars now. The mistake in this thinking is that Mars is seen as a valid option. Unfortunately, we truly are not ready for Mars yet. Neither the political will nor the technological expertise exists to send humans to Mars.

It is becoming recognized that the variable specific impulse (VASIMR) plasma rocket is a prime contender for a human Mars mission. However, VASIMR technology is far from operational and the impression some hold that "Mars is just around the corner" is inaccurate. Additionally, VASIMR and all Mars surface plans require nuclear reactors, a requirement which may be unable to overcome political barriers anytime in the near future. Even if VASIMR is not used, all Mars plans do require the development of a new (Saturn

V/Energia class or superior) super-heavy lift booster. There currently is virtually no Congressional support (and hardly any NASA support) for development of this booster within the next five to ten years.

There are also unresolved concerns in the areas of radiation protection, food shelf life, equipment repair, physiological reconditioning, surface base assembly, and many others. Many of solutions to these problems should be verified and utilized in a low gravity, remote environment prior to entrusting them to a Mars mission. Such verification tests assume an already existing lunar presence capable of facilitating such tests. Pathfinder seeks to lay the groundwork for an infrastructure capable of supporting such developments.

Another key arena that must be proved before proceeding to Mars involves the unexpected. It has been said that our ability to send missions to Mars and beyond depends heavily on robust systems capable of dealing with the unexpected and multi-functional tools for dealing with the unexpected.[4] The unexpected is the key issue. Unexpected events occur almost routinely in human space missions. In Earth orbit, a full mission support team is available to help the astronauts resolve the situation. Proposed solutions are choreographed and tested on Earth before astronauts are allowed to proceed. There is real time direct communications as the astronauts attempt a resolution. In most situations if no solution can be found, the mission can be aborted and the crew can return safely to Earth. The key things lost at Mars are communications and the ability to abort the mission. The distance is so great that real time communications will not be possible. Also due to the distance, there are no aborts – a Mars crew cannot abandon the base and return early. Before we send crews to Mars we need to understand what can go wrong on a surface base and prove our ability to resolve unexpected crises. The moon is a location where such operations can be tested.

Why have space efforts disappointed?

If there are so many reasons and opportunities to be in space, and even a federal mandate to be in space, why have space efforts often disappointed? Many see the space program as an endeavor that costs too much and accomplishes too little. Frequently, there is a divergence in goals that can create problems. Fundamentally, there are often two types of people involved in the space program. On one side (typically the NASA or contractor engineer) is the "Space Advocate." On the other side (typically the members of Congress and the President) is the "Governmental Administrator." These two often have different goals for American space activity, which leads to clashes in program development and budget appropriations.

The Space Advocate is the type who wants to climb the mountain because it is there. This person has an innate desire to explore space and expand human presence into space. He or she appreciates the benefits we gain from the utilization of space, but would favor space exploration even if there were no gains. The thrill is in the journey, so to speak.

The Governmental Administrator has no such love for the journey. He or she is only concerned with protecting and advancing the interests of the United States of America. And that is fitting, for that is the role of the government. This person appreciates the benefits gained from the utilization of space, but prioritizes those benefits among other endeavors. The metric used is how do these benefits advance the interests of the nation?

Since the beginning of the space program, these two factions have engaged in an intricate dance to try to find common ground. Unfortunately, that dance has often included false or unrealistic promises to garner support. Advocates often promise spacecraft designs that can do anything, when in reality they can do only a few things. Administrators promise and sometimes even legislate directives for space utilization that ultimately cost far more than the Administrators are willing to spend.

During the Apollo era, the two were largely united as the Advocate desire to explore space was coincidentally matched with the Administrator desire to demonstrate American technological superiority over the Soviet Union. The successful landings on the moon ironically destroyed this alliance, however. The Administrators had achieved their goal and had nothing further to gain from lunar landings. The Advocates, on the other hand, had merely seen their first step accomplished. Its success spurned them on to grandiose dreams of space colonies, Mars exploration, and lunar cities. To this day, Advocates are struggling to understand why the Administrators "turned their backs on them," not fully grasping why support existed for the Apollo program and thus not understanding why that level of support does not exist today.

Another source of disappointment is the reality that political management of a technological endeavor is a dubious prospect at best. American politics is grounded in the arts of compromise, lobby, and coalition building. Technological enterprises are based in the laws of physics, thorough analysis, and relatively inflexible design. The two do not mix well, especially when these differences are not taken into consideration.

Even once the Advocates and Administrators have agreed on a space initiative to support and funding has been authorized, and even when all technological challenges have been resolved, program expenses can still grow out of control, causing disappointment and resentment among the Administrators. Many times, space programs become bloated for the purpose of job security. The temptation is great (for both civil service and contractors) to involve an entire office in a study, even if one person can do the job, thus justifying (to the Administrator) the existence of the office. Many excuses are given: that it is necessary to maintain the skill level of all employees; that we should never be dependent on the technical competence of any one person; that multiple sets of eyes are needed to verify data; etc. These are all true, but the result is a semi-uncontrolled growth of project size (and indirectly complexity, sometimes even increasing the potential for error). The project then costs more than it would otherwise have cost.

The result of all of this is massive, underachieving projects whose destiny is cancellation. Almost ALL human space programs are eventually cancelled. The only exception to date is the Space Shuttle. (It should be pointed out that while the Shuttle is not yet cancelled, replacements are already on drawing boards and it is only a matter of finding Congressional spending approval.) Even ISS assumes cancellation and is designed with termination in mind. A true ongoing station would assume orbital replacement of all components, rather than an eventual deorbiting of the complex.

Issues relating to NASA budget cycle

Some of the disappointments with NASA space activities can also be traced to the budget cycle used to get funding from Congress. The NASA budget cycle is a three-year process of budget formulation, budget enactment, and budget execution. Budget formulation begins in January of each year with economic forecasts and general guidelines from the Office of Management and Budget (OMB). A final NASA budget is submitted to OMB in October to be incorporated into the President's proposed budget, which is generally submitted to Congress in the following January. Congressional review generally lasts until the end of the summer or October.[3]

Some problems are induced by this structure that can affect the space mission design process. With annual funding, there is a funding control gate for all programs at the beginning of every fiscal year. This, of course, places constraints and risks on the design process. A change in political alliances or public opinion could easily cause Congress to change the level of funding allocated to a spacecraft project under development. An engineering design is inherently inflexible to this sort of activity, as evidenced by costly, sometimes annual redesigns to the International Space Station throughout the previous decade. Another problem is that the NASA budget must compete with other federal agencies under the OMB for funding, including highly dissimilar agencies such as the Social Security Administration, the Veteran's Administration, and the Department of Housing and Urban Development.[3]

This has caused serious problems for the International Space Station from the beginning. The space station has been subjected to major redesigns at least seven times.[3] Congressional opponents attempt to kill it during each budget cycle. It has gone from an eight-person station down to a four-person station, up to a six or seven-person station, and lately back down to a three-person station. Even today, ISS designers at the Johnson Space Center cannot say with true confidence what the final configuration of the station will be, primarily due to the budgetary uncertainty.

President Bush's proposed 2002 budget considers the station "US Core Station Complete" when Node 2 is delivered on flight 10A. The impression is that American station components scheduled for delivery after Node 2 are no longer guaranteed. "U.S. contributions to such capabilities will be dependent on the availability of funds within the President's five-year budget plan for Human Space Flight, technical risks, and the Administration's confidence in Agency cost estimates."[5] Threatened components include the US Habitation Module, Crew Return Vehicle (thus limiting the station to a three-person crew), and Russian Program Assurance contingency modules (Interim Control Module, US Propulsion Module).[5] This "Core Station" ISS will never be able to accomplish all of the things the full station would have attempted. It will inevitably become a source of disappointment for those who planned to utilize the full capability of the station.

This budget cycle must be considered in the development of future space projects. A space vehicle is an integrated system. When a budget change forces the elimination of a component, adjustments must be made, which can sometimes mean a redesign of the entire vehicle. Generally, such redesigns increase the cost, delay the mission, and increase both the technical risk for mission success and the risk for further budget reductions and perhaps even program cancellation. Rapidly paced projects are much more likely to survive the budget process. The more times a project faces Presidential and Congressional review, the more opportunities exist for vital funding to be removed. Thus, there is a rationale for programs that can be implemented reasonably quickly.

What should we do if we go?

Having established that there are valid reasons to go to the moon, a specific plan should next be discussed. Simply launching forward unconstrained with only a general consensus to send humans to the moon would inevitably bloat into the most massive undertaking in human history. A specific concept must be established with rigid mission parameters. Once the design is begun, these parameters should not be changed. "Changes of mission parameters of almost any type have potentially large effects upon the specifications for the subsystems which compromise and support a spacecraft."[6] Even details as small as orbital inclinations are significant. "The specific orbit adopted for a mission will have a strong impact on the design of the vehicle."[6]

So how should we go? Big? Small? National? International? Many of the issues discussed previously in this paper suggest that a lunar mission should begin with a small initial presence. From three perspectives – technological, political, and commercial, it is counterproductive to begin with a large program. A small, "pathfinder" program can prototype and field test issues to build confidence before massive infrastructure resources are committed. From a political perspective, it is better for this small mission to be American. Later expansions can be international, but by going first and laying the foundation, America establishes itself as leader and sets the ground rules for lunar use.

The first step in the development of any space mission is to develop a mission statement and mission objectives. These drive the entire design process, as they describe what the mission is supposed to accomplish. For this Lunar Pathfinder concept advocated in this paper, the mission statement is to establish a human operational presence on the moon and provide a starting point for permanent occupation and utilization of the moon. Pathfinder Preliminary Mission Objectives are as follows:

1. Land people on a lunar polar region, sustain each crew for a period of one month, return them safely to Earth, and rotate new crews through the lunar facility on a periodic basis
2. Develop an expandable lunar surface infrastructure to support future lunar launch, landing and construction endeavors, including road surfacing, trench excavation, and landing site preparation
3. Study the effect of low gravity on human health and performance
4. Locate and survey potential lunar fuel resources
5. Process lunar fuels to prototype possibilities for use in support of future space activities
6. Return raw and processed fuel samples to earth for detailed analysis
7. Provide an environment capable of supporting Mars related testbed activities
8. Demonstrate that human space missions can be conducted in a cost effective manner
9. Develop and demonstrate American competence in human spaceflight beyond the gravitational influence of Earth

Specific rationales for each mission objective will now be discussed.

1. Land people on the lunar polar region, sustain each crew for a period of one month, and return them safely to Earth, and rotate new crews through the lunar facility on a periodic basis

During the Apollo missions, crews stayed on the lunar surface for only a few days. Of course, very little could be done in that time. A one-month stay is important in that it allows more useful time for mission activity to be conducted. This is an increase over the Apollo mission durations, but it does not begin to approach the long timeframes anticipated for most Mars mission concepts. Such a stay begins human operational experience on another surface in a small step. Future lunar programs could gradually increase the mission duration and set endurance records as confidence grows.

It should also be noted that the time period of one month happens to match the moon's rotational period. At a polar site this is not of particular importance, though it will be relevant for landings on other locations of the moon, which are subject to tremendous temperature variations between day and night and significant energy storage/production considerations. In those locations, maintaining a human presence throughout the lunar day/night cycle forces the development of a capability to inhabit the moon throughout its temperature extremes and provide continuous power, which will be necessary for any permanent lunar development.

2. Develop an expandable lunar surface infrastructure to support future lunar launch, landing and construction endeavors, including road surfacing, trench excavation, and landing site preparation

While the Apollo program produced a wide variety of scientific discoveries, it was never a design goal of the Apollo missions to leave the lunar surface more accessible to future human expeditions. As a result, Apollo did little to increase our capability for future human lunar activity. The same logistical issues present in each Apollo landing remain present for any future lunar landings.

Many extensive lunar concepts (FLO, LUNOX, etc.) face the obstacle that they require too elaborate a support infrastructure to be practical. Landing hazards due to uncertain terrain and possible rock obstacles are a driving concern and risk factor of every lunar landing. Long duration missions must be buried underneath regolith for radiation protection. Components for most modular bases must be transported from their landing vehicle to the base location and assembled. The lack of smoothed roads or pathways for transport vehicles to move base components from a landing site to a base location complicates any discussion of base assembly. Inflatable structures may need to be outfitted after arrival with equipment transported on a separate landing vehicle. Additionally, items to be tested in support of a Mars mission may require pre-existing infrastructure support.

Of course, the Apollo program could not have addressed these issues because each Apollo mission utilized a different landing site and there was no reason to assume any future lunar programs would revisit an Apollo site. However, it is reasonable to conclude that expanded human facilities will eventually be constructed at a Pathfinder site to support a fuel processing operation. By utilizing the Pathfinder presence to prepare the lunar surface for future bases, the design of those bases and their associated delivery systems can be simplified, reducing both the cost and the technical risk.

3. Study the effect of low gravity on human health and performance

Microgravity experience has demonstrated that the human body is affected by a lack of gravity. It is important to determine if these same effects are experienced in a reduced gravity field and develop appropriate countermeasures before committing personnel to a multi-year Mars expedition. Additionally, human factors studies have identified work environmental issues present in microgravity that are not present, or result in different actions, in normal gravity. It is important to determine how low gravity will affect human performance prior to committing to work station hardware for a Mars mission.

4. Locate and survey potential lunar fuel resources

It can be shown that significant savings can be accomplished by fueling interplanetary spacecraft with fuel mined on the moon as opposed to with fuel mined on Earth.[7] (The lower the fuel Isp the greater the advantage.) The chemical propellant (LH_2,LO_2) version of the Mars reference mission in particular can cut roughly sixty-six percent of its required fuel if it utilizes hydrogen and oxygen from lunar ice resources.[7] Achieving these savings in the reference mission or in any future interplanetary mission requires the presence of a lunar mining operation. However, prior to the establishment of such an operation it is important to physically confirm the presence of fuels at suspected sites, survey these sites to determine appropriate mining and processing locations, and validate proposed fuel processing techniques.

5. Process lunar fuels to prototype possibilities for use in support of future space activities

By building the technology to turn lunar resources into usable fuel, Pathfinder can bring Mars and other deep space human missions closer to an achievable reality. Experimenting with fuel prototypes will allow astronauts to explore a wide variety of processing technologies and select those with the greatest promise for future use.

6. Return raw and processed fuel samples to earth for detailed analysis

Study of raw samples may reveal alternative methods of fuel extraction, which may be simpler, more cost efficient, or require fewer resources than previously anticipated methods. This insight should be gleaned before committing to specific techniques in support of an operational fuel processing facility on the moon. Studies may also yield insights about the moon that might not be obvious with the equipment available on the surface. ISS and Earth will both provide more sophisticated laboratories for this research, allowing samples to be studied in greater detail. Returning samples to Earth will also allow for the testing of various storage devices, which will be necessary for any large-scale utilization of lunar fuel.

7. Provide an environment capable of supporting Mars related testbed activities

As has been previously stated, the Moon provides an ideal location for the evaluation of some Mars components. There is, of course, no place other than Mars where the Martian gravity, atmosphere, and radiation environment can be represented. However, in many aspects, the moon is a much closer approximation than any location on Earth or Earth orbit. Further, tests at Pathfinder can be aborted if necessary, with no risk to crew and no possibility of stranding astronauts away from Earth. The Pathfinder outpost should be expandable; such that Mars test articles can be landed at the facility and tested by Pathfinder personnel.

8. Demonstrate that human space missions can be conducted in a cost effective manner

Human space flight has come to be perceived as impossibly expensive and it is almost expected that any mission will inevitably go over budget and fail to meet its design timelines. There is also an inhibiting myth that human space travel beyond Low Earth Orbit (and in some cases even there) is too expensive for a single nation. A lunar program such as the one proposed here is not too expensive for one nation, and in fact is less expensive than the American contribution to the International Space Station.

Of course, in order to prevent the traditional cost explosion, it is necessary to control all aspects of the program, including staffing, from the project's inception. Success will provide lessons for larger space projects, such as the Mars expedition. It will also inspire public and congressional confidence in NASA's ability to implement such projects. Success will further help empower private industry to expand into the lunar arena for industrial, service, recreational and other enterprises.

9. Develop and demonstrate American competence in human spaceflight beyond the gravitational influence of the Earth

It is important to ensure American technical competency in all aspects of human spaceflight. Only by actually designing, constructing and operating hardware does a nation truly gain technical competency. For instance, while the theory of orbital refueling is well known, only the Russian space program is currently capable of refueling spacecraft in orbit. It is important to the overall vitality of the American space program that we possess this capability as well. Not for the sake of competition, but for the simple need to be truly functional and not dependent on other nations for critical components of future space operations. Implementing the technology to sustain humans on an extended lunar presence will ensure American technological growth vital to future space efforts.

Further, we cannot anticipate the status of foreign relations or the economic vitality of foreign nations over the next ten to twenty years. Political or economic instabilities could render current allies and partners into enemies, competitors, or otherwise non-participants. The loss of relations with such nations must not compromise American space interests. The risk of dependence on foreign nations for critical vehicle elements has already been seen in the space station program. While this risk will be necessary for many future space activities, it is an unnecessary risk for a program of this scale.

Keep in mind, however, a national Pathfinder effort does not preclude an international lunar presence. It is absolutely reasonable to expect that an expansion of a human lunar presence will at some point become international in scope. Pathfinder could itself become involved in supporting an international lunar presence by either becoming core modules for a future international surface base, or by serving as an outpost to prepare a base location for such a future international endeavor. Alternately, an international base could be developed independently of Pathfinder activities, simply using lessons learned from Pathfinder. Regardless of the manner in which international activity spreads to the moon, Pathfinder can play a role in building the international space infrastructure while simultaneously ensuring the development of American technological competence.

In addition to mission objectives, it is also necessary to specify requirements and constraints that the Pathfinder program must satisfy. These requirements and constraints provide structures that keep the program from attempting to "do everything" and provide guidance to design teams to ensure that Pathfinder is capable of meeting its mission objectives. The following are Pathfinder mission requirements and constraints:

1. Assume no heavy launch vehicle development
2. Available launch vehicles limited to existing vehicles, plus Delta IV and Atlas V
3. Minimize the development of new space vehicles
4. Implement intelligent, semi-autonomous navigation systems
5. Have the ability to receive ISS and STS support but be capable of operating with neither
6. No more than 1-3 billion increase in NASA annual budget for Pathfinder activities (both construction and operational phases)
7. Five to ten year development timeline from concept to first crew landing
8. Ten year design lifetime
9. United States mission with limited to no foreign participation
10. Minimize ground operations support team (flight controllers, program offices, etc.)

Specific rationales for each requirement or constraint will now be discussed.

1. Assume no heavy launch vehicle development

Implicit in many human space flight studies is the assumption that a new heavy lift vehicle will be developed in support of the human exploration program. Human spacecraft, stations, and planetary outposts are often sized beyond the capabilities of current vehicles with the assumption that the development of boosters to launch them is a logical given. In reality, however, new launch vehicles are unlikely without serious governmental mandates to develop new launch capabilities. Such vehicles could become exceedingly large programs, potentially larger than Pathfinder itself. Pathfinder will therefore be sized such that no new launch vehicles will be necessary to place a Pathfinder sized program on the moon.

2. Available launch vehicles limited to existing vehicles plus Delta IV and Atlas V

Numerous commercial launch vehicles are in various stages of design, but Pathfinder will not be designed to rely upon any of these vehicles, which may or may not exist in reality when it is time to launch Pathfinder components. While these vehicles are not so much dependent upon Congressional support, foreign markets, technological issues, and other unpredictable factors could affect their readiness. If such boosters are not ready on time, their delays must cause no schedule slips to Pathfinder. Boeing's

Delta IV and Lockheed Martin's Atlas V are not yet operational, but both are far enough along in their development and engine testing sequences that each can be considered a nearly existing system, one that can with confidence be expected to be functional before Pathfinder. Consequently, those two systems can assumed to be available and Pathfinder will be designed to take advantage of their projected payload capacities.

3. Minimize the development of new space vehicles

Each new vehicle that must be developed increases the cost (both political and economic) and risk of Pathfinder. Using existing vehicles allows Pathfinder to sidestep political discussions and development challenges that could prove damaging to the mission. Existing engines, spacecraft, and other subsystems will be used wherever advantageous.

4. Develop intelligent navigation systems with maximum possible versatility

Such systems reduce the ground operations support required by Pathfinder, which will significantly reduce ongoing operations costs. Additionally, such intelligent systems are necessary for future missions beyond the Earth-moon system and successful validation of those technologies will help to reduce the risk of future space exploration.

5. Have the ability to receive ISS and STS support but be capable of operating with neither

Pathfinder should utilize existing space systems wherever possible for maximum flexibility, but should not be tied to the availability of any particular space infrastructure. ISS may prove too limited to provide reliable support to the Pathfinder program. Additionally, the shuttle fleet could be grounded during a Pathfinder mission. Neither scenario should stop Pathfinder from proceeding or disrupt a Pathfinder mission in progress.

6. No more than 1-3 billion increase in NASA annual budget for Pathfinder activities

A return to the moon is a major endeavor and no amount of cost cutting measures will trivialize the budgetary resources necessary to conduct such a mission. Yet, given the need for ongoing shuttle, station, aeronautics, and robotic missions, it would not be prudent to expect Congress to devote more than a few billion of NASA's annual budget on initial lunar exploration. (This constraint may be revised slightly once cost estimates are performed, should it prove to be unrealistic.)

7. Five to ten year development timeline from concept to first crew landing

This cannot be a program where civil servants and contractors devote their entire career to seeing it launch – as has been done in both shuttle and station programs. A primary cause of costs spiraling out of control is the extension of program development well past the intended launch dates. This program is relatively small in size and scope and if it cannot be launched in a reasonable period of time, then perhaps that is evidence that technology has not reached an adequate point of maturity for the project.

8. Ten year design lifetime

This is a sufficient period of time to obtain sufficient science/engineering results to determine future priorities. A life span, including scheduled major research initiatives, should be planned out early in the design phases to ensure that the program is properly designed for all issues generated by its operations.

9. United States mission with limited to no foreign participation

It is often stated that space missions are so expensive that no one nation can conduct them alone. While that may be true for some nations it has never been true for America. A simple glance at other major American initiatives (Panama Canal, Hoover Dam, Strategic Defense Initiative, National Missile Defense etc.) reveal that America has always been capable of, and committed to, greater expenditures than human space projects such as Apollo, the Space Shuttle, and Pathfinder. Space missions are expensive, and it is perhaps easier to share costs, but using the International Space Station as an example, it is arguable that the original Space Station Freedom concept would have ultimately been less expensive for America than the final US contribution to the International Space Station Alpha. In truth, international missions allow the participating countries to participate in space activities that require a greater level of commitment than what their respective governments are willing to provide.

International participation increases the number of organizations that will have the ability to add cost, risk and complexity to mission requirements, while decreasing the areas in which the Untied States can provide technological leadership and maintain its current expertise. Where political considerations advise doing so, it may prove necessary for Pathfinder to use some international participation, but in all other situations the program should be strictly American. There is significant room for international expansion beyond the initial capability and the National Air and Space Act does provide for international participation. International outposts could be landed at the Pathfinder site, incorporating crews and experiments from multiple nations. Pathfinder should ideally be the vanguard of an international "city" on the moon. However, the basic Pathfinder mission should be American.

10. Minimize ground operations support team (flight controllers, program offices, etc.)

Operations are often the largest ongoing cost of a space program. The space shuttle and space station programs both have large mission control teams, program offices, configuration management teams, etc. Flight control teams should be limited to front rooms only, during all mission phases. This implies a need for highly sophisticated onboard software for mission management and systems monitoring. Mission-specific software parameters should be calculated by the onboard software, rather than by ground computers, wherever possible. If this can be accomplished, staffing costs can be significantly reduced. Program offices should be kept small and be given sufficient authority to enforce cost controlling measures.

Conclusion

There are immense challenges and opportunities on the moon that await human response. This paper has served to highlight some of those issues and bring out some of the rationales that support a small NASA mission to conduct some of the preliminary research necessary for society to meet these challenges and take advantage of the numerous lunar opportunities. It is clearly in accord with the National Air and Space Act, and in the best interests of the United States and ultimately the world, for NASA to proceed immediately with a lunar Pathfinder-type mission.

References

[1] The National Aeronautics and Space Act. Pub. L. No. 85-568, As Amended. http://www.hq.nasa.gov/ogc/spaceact.html.

[2] Schrunk, D., Thangavelu, M., Cooper, B., and Sharpe, B. (2000). "A Coherent Vision for Space Exploration and Development in the 21st Century." Proceedings of the 2000 Lunar Development Conference. Space Front Press.

[3] Hammond, Walter. (1999). Space Transportation: A Systems Approach to Analysis and Design. AIAA.

[4] Larson, W. and Pranke, L. (Eds.) (1999). Human Space Flight Analysis and Design. McGraw Hill.

[5] National Aeronautics and Space Administration Federal Funds. http://www.whitehouse.gov/omb/budget/fy2002/nsa.pdf.

[6] Fortescue, P. and Stark, J. (Eds.) (1995). Spacecraft Systems Engineering. John Wiley and Sons.

[7] Howard, Robert. (1999). "Performance Benefits of Utilizing Lunar Fuel in Support of Human Interplanetary Space Missions." Proceedings of Human Space Transportation and Exploration Workshop. AIAA.