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Visions of exploration

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Abstract

The word ''exploration'' threads its way through every discussion of human space flight and often headlines national policy statements about the US space agency. Yet this concept, so rooted in our culture, remains remarkably ill-defined. In this paper, we examine various presumptions implicit in the term and its ramifications for federally supported space endeavors. We argue that historical examples of exploration, widely used by policy makers, often make poor models for contemporary space travel. In particular, historical precedents of exploration set up a land-biased view of discovery, a restriction which impedes full expression of the Vision for Space Exploration and its possible scientific returns. These same precedents also set up a view of discovery that is biased toward *in situ* human presence, a view that modern technology is rendering increasingly absurd.

1. Introduction

''Exploration'' is a word that is intimately associated with discussion of human space flight and national policy statements. For example, the White House laid out ''The Vision for Space Exploration'' (VSE), as per the National Security Presidential Directive NSPD-31 in January 2004 [1]. This document paved the way for the new Exploration Systems Mission Directorate at NASA as the agency implementer for at least the human space flight part of what was commonly abbreviated as the President's Exploration Initiative. The fundamental goal of this vision is to ''advance US scientific, security, and economic interests through a robust space exploration program.'' The word ''exploration'' also permeates the NASA Strategic Plan and budget proposals, as well as Congressional oversight of the agency (see Fig. 1). It appears almost a thousand times in the NASA budget proposal. As expressed in these documents, ''exploration'' is both a rationale and justification for the task that NASA has been congressionally authorized to perform. It is a key defining term in the agency charter, which identifies ''space activities'' as those required for the ''exploration of space''. The purpose of this essay is to examine the underpinnings of the word ''exploration'' as it applies to our efforts in space.

Current US space policy has come of age in the shadow of the *Columbia* disaster, an event which has also advanced specific, if implicit, ideas about exploration. For example, the Columbia Accident Investigation Board (CAIB) reported that ''The crew members lost that morning were explorers in the finest tradition, and since then, everyone associated with the Board has felt that we were laboring in their legacy''. The loss was of more than astronauts and national pride, but of ''explorers''. This tragedy, and that seminal report, led to the VSE a year later. The 2004 *President's Commission on Implementation of United States Space Exploration Policy* (the Aldridge Commission) was chartered a week after the announcement of the VSE to make recommendations on the implementation of that vision. They noted in their report that ''Science and exploration are synergistic: science is the attempt to explain nature, while exploration is the establishment and pushing back of a frontier'' [2]. In fact, panel member Neil Tyson recalled to the present authors that one of the first decisions this committee reached was that exploration was not identically science. While synergistic, and not identical, a distinction between the two activities can be considered

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Fig. 1. A ‘‘word cloud’’ constructed from the 2006 NASA Strategic Plan, which is the most recent such document for the agency. The size of the word is proportional to the frequency with which that word is found in the text. (The acronym ‘‘NASA’’ and the words ‘‘space’’, ‘‘agency’’, and common words are excluded here.) This figure illustrates graphically the importance of the word ‘‘exploration’’ in the very picture the agency has adopted for what it does. Few of the other primary defining words for the agency have such flexible interpretations. The authors thank the creators of Wordle for this representation.

simplistic, in that science can be considered to be establishing and pushing back an intellectual frontier.

The optimal strategy for US space exploration has recently been the subject of some decidedly revisionist thinking, manifested in the February 2008 workshop ‘‘Examining the Vision: Balancing Science and Exploration’’ sponsored by Stanford University and the Planetary Society [3]. Human space exploration was defined implicitly by the participants with an implementation plan – to wit ‘‘the purpose of sustained human exploration is to go to Mars and beyond’’. This, and also the view that science is a beneficiary of human space flight but is not its primary motivation, is consistent with the thinking of the Aldridge Commission. This consistency became a matter of revisionism here because, following the Aldridge Report with its broad set of science goals, the NASA exploration enterprise subsequently became narrowly focused on lunar return.

While these statements provide context, they do little to advance our deeper understanding of exploration and its implications for space policy. The CAIB report defined Columbia’s astronauts as explorers even though the crew never left low-Earth orbit, a region traveled by hundreds of other astronauts prior to STS-107. In what sense then were they ‘‘pushing back … a frontier’’ as specified in the Aldridge Report? Or is the notion of exploration as travel to places never visited too limiting? After all, Sir Edmund Hillary and Tenzing Norgay’s ascent of Everest brought them to a place never visited, whereas Charles Darwin followed in the footsteps of hundreds of others when he made his world-changing discoveries in the Galapagos Islands. Does this make Hillary and Norgay explorers to the exclusion of Darwin? [4].

Despite these ambiguities in meaning, it is still emphasized by many that the USA is a nation founded by explorers, and that, however troubling their legacy might be, those explorers have instilled in us a national ‘‘spirit of exploration’’. A discussion about the definition of ‘‘exploration’’ can, in principle, devolve into a comparison of dictionary definitions, and that is not very satisfying. Were we to do this, we would quickly find that the verb ‘‘explore’’ is defined (as per the Oxford English dictionary) as to: (1) travel through an unfamiliar area in order to learn about it; (2) inquire into or discuss in detail; and (3) examine by touch. Two of these would apply to human space flight. By these definitions, one might argue that exploration involves little more than walking into the woods a few hundred yards from home and planting tracks on a few square inches of ground that might never have been touched by human feet. This seems absurd, of course. Such definitions could even be rendered irrelevant by Chief Justice Potter Stewart’s ‘‘I know it when I see it’’ test (which he famously used to define obscenity) [5]. Such a test, in which exploration is defined at gut-level, seems endemic to practical modern views of space exploration. Yet it is an absurdity which makes the point clear: definitions offer little help in understanding the constellation of meanings which surround modern exploration [6].

These may seem like semantic questions, but there are perils which await the US space program if it chooses to base a program on exploration, and yet leaves the meaning of the word unexamined. As NASA moves from policy statements to implementation goals and mission metrics, the ambiguity of exploration continues to play out in debates over goals and outcomes. The question for NASA is not ‘‘What is the true meaning of exploration?’’ but rather ‘‘What kind of exploration should we pursue?’’ We do not presume to answer either question here but, rather, hope to prepare the way for the debate which must follow: first, by looking at the different meanings of exploration and their historical precedents; second, by examining some of the hidden assumptions in exploration policy and its implications for the VSE.

2. Exploration and the historical record

The historical record offers a rich set of examples of what we call exploration: Christopher Columbus sailing to the New World, Roald Amundsen driving his dogs towards the South Pole, and Neil Armstrong stepping into the soft dust of the

Moon. Yet these examples illustrate the difficulty in pinning down exploration as an activity. If we define exploration as travel through an unfamiliar area in order to learn about it we exclude Columbus, whose discovery was serendipitous rather than purposeful. We would also have to exclude Amundsen and Armstrong, and indeed many of the pantheon of explorers, who tended to dash across new terrain rather than investigate it systematically. Even more expansive terms such as ''discovery'' sometimes offer a poor fit for the object of modern expeditions: did Robert Peary discover the North Pole in 1909, an axis point that Greek astronomers knew about 2500 years ago? Not in any meaningful sense of the word. Students of exploration, then, must make peace with this uncomfortable fact: ''exploration'' is a multivalent term, one which has been (and undoubtedly will continue to be) used in different ways by different people. Geographical discovery, scientific investigation, resource extraction, and high-risk travel are activities tucked inside this definitional basket.

Because of exploration's multiple historical meanings, policy makers and administrators have often used this history selectively and out of context. Specifically, policy statements cite the history of exploration in order to make two points: first, that humans are compelled to explore, that curiosity about the world is an innate attribute of our species; and second, that this compulsion has expressed itself most fully in the USA, where exploration has moved beyond matters of trade and settlement to become a part of national identity, a symbol of American idealism, enterprise, and self-sufficiency [7].

2.1. The impulse to explore

Let us take these ideas in order, starting with the human impulse to explore. We cannot deny that the history of our species is a history of motion. We are all the children of travelers: of long migrations out of Africa, oceanic crossings, and continental traverses. Archeological evidence suggests that humans spent most of their prehistory, from 120,000 BCE to 10,000 BCE, on the move. We bear the marks of these migrations in the foods we eat, the languages we speak, and the places we live. Indeed, we carry traces of our itinerant past inside of us, in our dietary preferences for foods salty and sweet, our peculiar anatomy and physiology, and our unique mitochondrial DNA, which, read carefully, offers us a road map of our ancestors' paleolithic travels [8].

Yet these facts, so well established, tell us little about motives. Human curiosity has a long and storied history. Aristotle begins his *Metaphysics* by stating ''All men possess by nature a craving for knowledge'', an observation borne out in the earliest works of human literature, from Eve's transgressions in *Genesis* to Odysseus's trouble-making in the *Odyssey*. Yet there is little evidence to suggest that humans traveled primarily, or even incidentally, because of curiosity. During the long millennia of our prehistory, the most obvious reason for travel was survival, following seasonal animal migrations, escaping harsh weather, and avoiding predators and, perhaps, other humans [9].

Evidence points to exploration – in all its incarnations of meaning – as a cultural or political activity rather than a manifestation of instinct. History's most celebrated voyagers – Pytheas, Zhang He, and Columbus – sailed from nations with imperial ambitions [10,11]. As Stephen Pyne points in his survey of the ages of exploration, ''There is nothing predestined about geographical discovery, any more than there is about a Renaissance, a tradition of Gothic cathedrals, or the invention of the electric light bulb'' [7].

The notion that exploration expressed deeper impulses, such as wanderlust or curiosity, came much later, during the 18th century Enlightenment, when voyages took up the systematic practice of science: gathering specimens and ethnographic data, observing celestial events, and testing geographical hypotheses. These expeditions expressed a genuine curiosity about the globe, yet they elicited state sponsorship only because rulers saw political value in discovery expeditions, a form of ''soft power'' statecraft that could enhance national prestige rather then add to colonies or imperial coffers [12,13].

If 18th century audiences came to accept the lofty trait of curiosity as a driving force behind voyages of discovery, 19th century audiences found deeper impulses behind humanity's urge to explore. In particular, the Romantic Movement gave rise to ideas central to the ethos of modern exploration. The first of these was that discovery is a process that includes, but is not contained by, practical pursuits. While geographical discovery, science, and resource extraction all have their parts to play, exploration has an intangible, ineffable quality that cannot simply be reduced to logical goals. The second idea (which follows closely from the first) was that the value of exploration is tied to the subjective experience of the explorer, a symbol for the nation at home [14].

2.2. Exploration in American history

By contrast, Lewis and Clark's 1804 Corps of Discovery did not carry much symbolic weight in the 19th century. While it succeeded in most of its scientific and political goals, the expedition returned with few specimens and was slow to publish its results. Consequently Lewis and Clark's exploits only became famous at the beginning of the 20th century. More broadly speaking, however, Americans had begun to accept the patriotic and Romantic meanings of exploration. As a result, the US government increasingly sponsored expeditions on missions symbolic as well as practical after 1830. Congress now looked to exploration as a means of enhancing national reputation, not simply a way to advance military or commercial objectives. Starting with the departure of the US Exploring Expedition to the Pacific in 1838, the USA pursued a series of international discovery expeditions. In these endeavors science remained an important expeditionary goal. US expeditions put on their best face, sailing with corps of ''scientifics'' to advance geographical knowledge and, in the process, to persuade other nations that the USA was more than a republic of untutored farmers. In short, pursuit of knowledge gave US expeditions symbolic heft. It ushered the United States into an enlightenment tradition of

imperial voyaging and – its organizers hoped – into the ranks of civilized nations [15].

As the USA became a nation of cities, railways, and stockyards in the late 1800s, Americans looked back nostalgically to their itinerant and expeditionary past, celebrating exploration figures such as Christopher Columbus at the World Columbian Exposition of 1893 and Lewis and Clark (who were still relatively unknown) at the Lewis and Clark Centenary of 1905. While 19th century Americans had been eager to identify themselves as people of culture and civilization, 20th century Americans were more inclined to revel in, and embellish, their buckskin past, weaving the idea of the frontier into a story of American progress. Historian Frederick Jackson Turner first advanced this idea in 1893 in his famous essay ''The Significance of the Frontier in American History.'' [16].

Today the Turnerian spirit is alive and well, reflected in the broad range of people and activities linked to exploration. As space historian Roger Launius argues, Turner's frontier thesis has been particularly popular within NASA. ''Americans have always moved towards new frontiers,'' wrote NASA Administrator James Fletcher in 1987, ''because we are, above all, a nation of pioneers with an insatiable urge to know the unknown. Space is no exception to that pioneering spirit.'' [17].

Yet this romanticized view of the American frontier does not apply well to the conditions of 21st century space flight. As historian Steven Pyne pointed out at the 2002 meeting of the American Association for the Advancement of Science, space flight lacks the drama of ''first encounters''. Robotic explorers ranging over abiotic environments may never have the drama of Stanley's encounter with Livingstone. ''With no distinctively human encounter possible, there is no compelling reason for humans to even serve as explorers,'' Pyne suggests. Historical antecedents, then, must be treated with care [18].

3. The ''insegreviousness'' of exploration

That Americans have broadly embraced exploration as a part of their national identity seems clear. Yet, as the above examples show, this embrace provides little insight into the meanings of exploration, the effect of such meanings on the planning of missions, or the value of such missions to the nation. Why does such an important term as ''exploration'' retain such ambiguity? One finds many answers, but perhaps comedian Gary Owen explains it best. Certain words, Owen states, are ''freedom words'', terms with meanings broad enough to label things that would be hard to categorize. Like Owen's made-up word ''insegrevious'', exploration has come to mean whatever its users want it to mean.

In truth, the ambiguity of the term ''exploration'' has certain advantages, particularly from the perspective of funding and policy making. Because funding of NASA budgets requires broad agreement in Congress, the fuzziness of exploration often avoids triggering debates that would weaken political support. ''In the political realm, it's not desirable to have too precise a definition'', according to Scott Hubbard, Stanford Professor of Engineering and Former Director of NASA Ames Research Center, with respect to exploration. Within this environment, explains Hubbard, defining exploration too narrowly ''is not without some peril''. Ian Pryke, Senior Fellow at George Mason University and Former Head of the European Space Agency's Washington Office, speaks in similar terms about the word. ''A little bit of constructive ambiguity never hurts.'' [19].

Yet this ambiguity comes with a price. If it makes it easier to craft policy and pass space budgets, it makes later decisions, such as policy implementation and mission metrics, more difficult. Five years after the announcement of VSE and four years after the Exploration Systems Architecture Study (ESAS), broad disagreement remains about core concepts in US space exploration. While VSE and the reports detailing and extending it deserve praise for being visionary and ambitious, they have also ''kicked the can down the road'', delaying, rather than resolving, debates about the ultimate goals of space exploration.

For space scientists such as Harvard astronomer Bob Kirshner, the concept of exploration is a form of field science. ''Exploration without science is merely tourism'', he remarked in his 11 July 2005 'Statement on the Role of Science in the Vision for Space Exploration' as President of the American Astronomical Society. The label of explorer as ''tourist'' – and its applicability to operations in low-Earth orbit – was picked up thoughtfully a year before by the British astronomer-astronaut Michael Foale in response to a 2004 question by journalist Keith Cowing [20].

> So, I am not going to quibble with the use of the word, but it certainly means that if we want to go onboard the ISS and spend 6 or 7 months working, as you say, in an environment that doesn't make you 'go anywhere', in that I am just floating from this side of the room to that side, and I get to know that small space very well. Am I exploring? No. But I am certainly exploring when I look out of the window and look down at the Earth and see the Himalayas go by, and I see Tierra del Fuego go by, and I see Spain, and Britain, and the United States. And I can see an awful amount that makes me feel like I am the greatest tourist – the greatest wanderer. Indeed, I am seeing a panorama that will beat any other view seen in any other circumstance when you are exploring on Earth. So, the sensations for a human being are extraordinary and I would never say that I was not an explorer in this context.

Taken to its logical conclusion, however, Foale's travel-as-exploration model also raises questions. Is an explorer merely a scientist who goes places? If science is the ultimate objective of exploration, what status is afforded astronauts who are not scientists? After all, they are no longer the only (or even the most efficient) means of conducting space science. Should we place them in the same category as robotic scientific travelers such as *Spirit* and *Opportunity,* which are surrogate explorers operated by the scientific explorers in Pasadena?

In a very broad sense Foale's sentiments might be considered consistent with the findings of the MIT Space, Policy, and Society Research Group in their December 2008 white paper, *The Future of Human space flight* [21]. This group struggled

with the rationale for human space exploration, and concluded that human space flight achieves its goals and appeals to the broadest number of people when it represents an ''expansion of human experience''. The expansion of human experience has value to a nation, they assert, as it might have value to an individual tourist. It should be noted, however, that the hundreds of astronauts who have traversed low-Earth orbit make that venue somewhat suspect as a new frontier to push back on. While it might be expanding Foale's experience, it probably is not doing so for humanity in general, and Foale is, to use Kirshner's word, perhaps more a great tourist than an explorer. MIT group leader David Mindell believes that, while this can represent value to the taxpayer and has resonance in Congress, NASA sometimes has difficulty using words like ''expanding human experience'' in framing its goals.

Yet, for others, humans remain vital to a modern vision of exploration. According to Planetary Society Executive Director Lou Friedman, exploration has to involve risk in distant places. Or, as he puts it, ''Exploration'' = ''Adventure'' + ''Discovery''. To him, astronomy with telescopes is perhaps not a form of exploration at all. Astronomers would be seriously perturbed by such an outlook, however. One might make the case that even for an astronaut standing on Mars, surveying terrain that represents this new frontier is using light to do so, just as astronomers use light to survey more distant frontiers.

Within the political sphere, space exploration gains its relevance largely through symbolism, both as a human quest and a geopolitical strategy. Of the half dozen campaign speeches that mentioned space flight at the 2008 Democratic National Convention, none mentioned science. For all of them space flight was useful as a measure of human (and more specifically American) achievement. In the Republican campaign arena, John McCain's policy statement about exploration was quite revealing:

> Although the general view in the research community is that human exploration is not an efficient way to increase scientific discoveries given the expense and logistical limitations, the role of manned space flight goes well beyond the issue of scientific discovery and is a reflection of national power and pride [22].

In the national conversation about the meaning of space exploration, not much has changed since the Augustine Commission considered these questions in 1990 [23]. ''Some point out that most space science missions can be performed with robots for a fraction of the cost of humans'', they said, ''and that therefore the manned space program should be curtailed. Others point out that the involvement of humans is the essence of exploration, and that only humans can fully adapt to the unexpected.'' Despite the impressive edifice of VSE, then, US space policy is being built on shifting ground.

4. Is it all about rocks?

So far, this essay has pointed out the range of meanings attached to exploration, a term so conceptually broad that it would seem to admit anyone with a geographical goal and a good pair of shoes. But exploration has hidden assumptions that restrict its meaning. For example, the objectives of the VSE involve traveling to places distinguished by land and landforms (e.g. Moon-to-Mars, and perhaps to Near-Earth Objects—NEOs) rather than to points in space. In this focus on rocky places, NASA is following in a long tradition of exploration.

Renaissance voyagers during the ''Age of Discovery'' viewed other lands — Asia, Africa, and the Spice Islands — as the goal of their voyages. Oceans, on the other hand, were treated as highways rather than habitats, a medium to traverse rather than to be investigated. Only in the 19th century did this change, as deep-sea exploration came of age. Yet even then many of these sea expeditions focused on the ocean floor rather than the watery world that covered it [24].

Twentieth century explorers have expressed this ''land bias'' too. When Frederick Cook and Robert Peary returned from their North Pole expeditions in 1909, their photos represented the North Pole, a geographical point in the middle of the polar sea, as a towering hummock of ice. Yet neither man had navigational equipment precise enough to determine the location of the North Pole so exactly. Nevertheless, both men saw fit to plant their flag on the tallest, ''rockiest'' mound of ice in the vicinity (see Fig. 2).

This penchant for visiting rocks in the name of ''exploration'' leaves many kinds of space science at a disadvantage. Certainly, for astronomy, it is well understood that free space is far more enabling for most telescopes than the lunar surface [25]. The Earth—Sun second Lagrange point, for example, is the operational location of choice for a host of new astronomy missions and mission concepts. This location, about four times the lunar distance anti-sunward from the Earth offers extraordinary thermal stability, with continuous power and line-of-sight communication. While it is often said that having humans on the lunar surface offers special opportunities for large science instruments there, it is rarely acknowledged that getting those humans onto the lunar surface is probably far more risky than getting them almost anywhere else in cis-lunar space. What if Lagrange points were culturally acceptable as prime targets for human exploration?

These Lagrange points provide extraordinary opportunities for getting places, as very low-energy pathways connect them across the Solar System. Astrodynamicists Martin Lo and Shane Ross described what they termed the interplanetary superhighway system, with junctions marked by planetary Lagrange points [26]. Such locations are remarkably enabling for interplanetary access. Early in the 2000s the NASA Decadal Planning Team came up with a strategy in which a ''Gateway'' station would be deployed at the Earth—Moon L1 point, 84% of the way from the Earth toward the Moon, that could link lunar surface activities (such as water and propellant mining) at low propulsion cost with a base on Mars [27,28].

The Gateway strategy for exploration was never adopted by ESAS. The historical precedent for that strategy is perhaps most closely polar exploration (where the site for conquest, if not discovery, was marked by dynamics rather than by mass). The

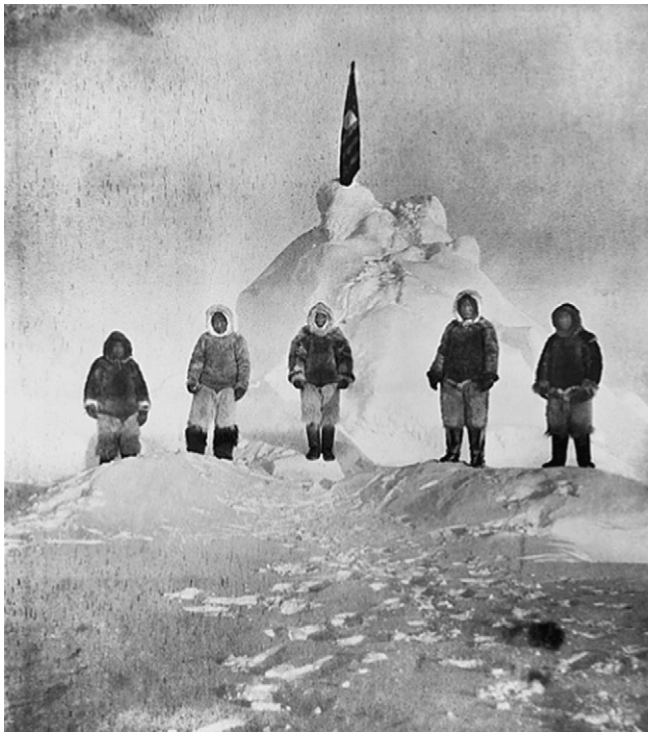

Fig. 2. This picture, taken by Admiral Peary, shows his crew at what they considered to be the North Pole. Although they believed that they had reached at least the general vicinity of the pole, they specifically chose to plant their flag on top of the nearest hillock of snow. This view, showing people covered in thick outerwear, heavy boots, with a ''helmet'' made of fur, at a site with no other life, and with deep footprints all around, is reminiscent of Apollo pictures from the lunar surface. This image illustrates the importance of local geography in exploration and discovery. The North Pole shown here was not just a virtual point in space where the Earth's axis of rotation crossed its surface, but was symbolized for these explorers by a mound of material. This land-biased view of exploration is part of our cultural heritage, and will make development of enabling locations like Lagrange points less attractive. Image copyright 2007 National Geographic Society, Robert E. Peary/National Geographic Stock (used with permission).

idea of a mid-ocean location that offered national value by occupation or conquest was inconceivable to early explorers as well. While these Lagrange points may be a lynchpin to our future plans, our expeditionary heritage has usually ignored places such as these where there is nothing material to be found.

The importance of going to places where there is ''stuff'' to find bears on the question thoughtfully articulated by John Marburger, Director of the Bush Office of Science and Technology Policy, at the 2006 Goddard Symposium, about the extent to which we want to commit to incorporating the Solar System into our economic sphere. This would be such that resources from space, whether they be material resources mined from rocky bodies, or even energy from solar radiation, become commercially available to us. Historical antecedents relate broadly here, as exploration (whether human or robotic) becomes a search for harvestable material riches that can empower a nation. Identification of such tangible benefits becomes, in many respects, a test for human colonization, in which an ability to disconnect from the Earth and live off the land at some faraway site can be considered a fundamental human destiny.

5. Whence a lunar return?

How much does this land bias influence the current goals of the VSE? As the Moon becomes the new, rocky grail of US exploration, which ''vision of exploration'' will the national strategy follow? NASA has made it clear that science has a role to play in the VSE. Yet, while the planetary science community has agreed that further studies of the Moon could offer new insights into the history of our Solar System and of the formation of our Earth, the scientific importance of *in situ* human exploration there, as opposed to robotic efforts, has not been convincingly demonstrated. What guides NASA's plan for extended occupation at a lunar ''outpost'' when access to widely spaced locations on the lunar surface, perhaps by robots, might be more useful for lunar science?

From scientific and budgetary points of view, one could make a case that NASA should abandon the human lunar outpost idea altogether and invest its money in telerobotic exploration of the Moon, a project that would cost a fraction of a manned outpost. The same can be said for the exploration of Mars. Even as NASA considers long range plans to send a human spacecraft to the red planet, Martian surface probes *Spirit*, *Opportunity*, and *Phoenix* have underscored the value of robotic exploration. While it has been noted that a human can do in one day what a robot can do in a month, it should be kept in mind that 30 robots would probably cost less than one human. If cost-efficient planetary science is our measure of mission success, robotic exploration has set the bar for VSE very high, and Moore's Law suggests that the bar is getting higher.

Yet comparing robotic and human exploration in this manner is of limited use. We can calculate how much robotic science could be done with a VSE budget, of course, but it is doubtful that Congress would ever authorize such vast sums for robotic exploration. For almost two centuries, the federal government has adopted a vision of exploration that is symbolic as well as practical. However impressive have been the gains of robotic exploration, it is unlikely that Congress or NASA will abandon human space flight on purely practical grounds to focus solely on scientific goals.

If human space flight has offered poor returns for science, it has paid off handsomely in symbolic and geopolitical terms. The maxim that ''the country that can put a man on the Moon should be able to…'' continues to resonate with the American public. Political stump speeches still reference the Apollo missions 40 years later. In addition to the national convention speeches mentioned earlier, President Obama's acceptance speech in Grant Park looked back admiringly on the Apollo Program: ''A man touched down on the moon, a wall came down in Berlin, a world was connected by our own science and imagination.'' [29].

Yet the Apollo program has also shown the dangers in framing a national space exploration program too much in symbolic and geopolitical terms. As much as human space flight continues to have geopolitical value, it is a value that has varied considerably over time. Like the price of stocks, it remains subject to changes in world events.

6. Conclusion

What to do? There are few easy answers. However, the history of US exploration offers insight about places we can start.

First, we should accept that ''exploration'' is a multivalent term, with many meanings, some of which are contradictory, and all of which have historical precedent. For too long we have looked at the history of exploration selectively, seeking to find the antecedents which justify our own vision of exploration: as science, as human adventure, as geopolitical statement. This is a definitional fight which cannot be won. Space policy must acknowledge the multiple visions for space exploration, developing a clear-eyed metric of value which avoids the vagaries of lofty ''exploration-speak''. If the merits of human exploration of the Moon and Mars are primarily symbolic and geopolitical, what are these goals worth in terms of federal funding? What are costs and benefits of missions developed to express ''soft power'' vs. science? Finally, which goals or combination of goals offers the best chance of long-term buy-in by the taxpayer? While historical precedent defines exploration in terms of human explorers who travel to new destinations, that definition is woefully obsolete with regard to discovery in an era in which teleoperation offers virtual presence for explorers who remain on the surface of the Earth. As has been pointed out by many authors, ''robots'' have come to be less personal assistants who follow us dutifully, and more expendable extensions of our senses. In this respect, science can be viewed as arguably the most important frontier for humankind, and whether it is done by humans *in situ* or by humans remotely is no longer a particularly relevant distinction.

Second, we must recognize that large-scale federally funded expeditions will continue to be ''hybrid'' missions, focused on a variety of goals. The Lewis and Clark expedition is a notable example of this. Since the late Enlightenment, state-sponsored expeditions have launched multipurpose expeditions for science, state craft, and symbolism. Key to the success of these earlier expeditions was not which vision of exploration they chose, but how effective they were in bundling them together. Twenty-first century space flight gains little from a battle between scientists and policy makers or proponents of telerobotics vs. proponents of human space flight. Space exploration will succeed or fail on the ability of mission managers to wear different hats, to accommodate multiple goals without having them impede one another.

Finally, we need to understand the implications of different meanings of exploration for long-term public funding. If purely scientific missions offer tangible benefits, they often fail to offer compelling ''storylines'' to excite the public imagination. While planetary landers and rovers can offer stunning storylines, these land-biased missions, with views of distant horizons, local landforms, and the night-day cycle, couple more clearly to the frontier myth that embellishes them. It is more difficult for heliospheric and astronomical science missions to achieve such allegorical return. By contrast, human space flight's geopolitical and symbolic power with legislators and the public must be balanced by the enormous price-tag it brings with it and its uncertain value with changes in global events.

Might there be more pragmatic ways of organizing a hybrid, long-term space program? VSE grew out of a symbolic vision of exploration that privileged human space flight over other goals. Some space scientists now seek to hitch their wagon to the VSE horse, a matter of frustration for many others. Meanwhile, policy makers worry about sustaining public and congressional support for such an expensive program, particularly in the current recessionary environment. Former Secretary Marburger's reach for incorporating the Solar System into our economic sphere is one pragmatic approach to such a hybrid program. The Aldridge Commission, in developing an implementation plan for the VSE, included a rich diversity of science that could be embraced in such a hybrid program. In spite of that, at least the near term exploration agenda has been largely lunar-centric.

What would it look like, however, if discovery served as the framework for long-term US space exploration? How might human missions be used to extend, or complement, scientific goals? How might such missions be developed to promote symbolic or geopolitical goals most efficiently without impeding the more stable, long-term values of science? This is not a prescription for change, but a starting point for talking about it.

That exploration has deep roots in human history is clear. Yet meanings of exploration continue to change. The models of Apollo, the Space Shuttle and the International Space Station – all conceived in an era before advanced telerobotics – now have limited value in predicting the future course of space exploration. Clearly, we will continue to link space exploration to earlier periods of travel and discovery. Yet we should be careful in what we take away from this record: if history offers stories rich in symbolism, it cannot provide a foundation for contemporary space policy. We now face a vision of exploration that is different from that of our ancestors.

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