The Case for a NASA Research Base on the Moon

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ABSTRACT

There is significant international and private-sector interest in the Moon, and there is likely to be significant activity on the lunar surface in the coming decades. U.S. national interests in the Moon mandate that NASA establish a long-term and continuous U.S. governmental presence on the Moon before international and private missions. The activities conducted at a NASA moon base would be to learn and demonstrate long-term operation of an extraterrestrial base; develop long-term life support systems at an extraterrestrial base; determine the long-term effects of 1/6 gravity on humans; develop the management and technical approaches that keep cost down, allowing permanence; conduct lunar geology and geophysics, astronomy, Earth observation, and other science as proposed and reviewed by the science community; and inspire students and the public. The U.S. Antarctic Program provides a useful analog for how a science program can be an important part of national policy. The U.S. Antarctic Program ensures that the United States has an active and influential presence in Antarctica, designed to support the range of U.S. Antarctic interests. The "Science Diplomacy" motivation, the unified organization within a federal agency, and the field operations of the U.S. Antarctic Program can all be applied to a NASA research base on the Moon. The key challenge to maintaining a long-term NASA base on the Moon is keeping the run-out cost to a fraction of NASA's total budget—I suggest 10% or less. The U.S. Antarctic Program operation within the National Science Foundation is about 5% of that agency's total budget.

INTRODUCTION

The Space Act of 1958 as amended commits NASA to human exploration as a part of U.S. national policy and as an important contribution to the scientific exploration of the universe. The Apollo Program is certainly the premier example of a NASA human exploration program directly motivated by U.S. national policy considerations while being an important science and exploration activity. It also inspired the nation and the world. The Apollo–Soyuz program, Skylab, and the present International Space Station (ISS) were all also a part of U.S. national policy, and all conducted science activities. Interestingly, the nature of U.S. policy evolved over the years of these programs, and international competitors in the Apollo era became international partners in the ISS program. New space-faring nations have now emerged that are not currently part of the ISS partnership—principally, China and India. These new actors and the addition of private-sector activities—the Google X prize, SpaceX, Orbital, and Golden Spike—add a new dimension to any assessment of U.S. activities in space. A key question for NASA and the United States is what are the future issues in U.S. national policy that should shape the NASA program.

The current international push to explore the Moon, sparked originally by the NASA Constellation Program, and the extensive private-sector plans for lunar missions must influence U.S. policy and NASA programs. In particular, in order to maintain U.S. influence on lunar activities, the United States should direct NASA to establish a permanent governmental presence on the Moon before any other significant foreign national or private-sector lunar missions. The activities conducted at this base would be to

1. learn and demonstrate long-term operation of an extraterrestrial base;
2. develop long-term life support systems at an extraterrestrial base;
3. determine the long-term effects of 1/6 gravity on humans;
4. develop the management and technical approaches to streamline operations and reduce costs, allowing permanence;
5. conduct lunar geology and geophysics, astronomy, Earth observation, and other science as proposed and reviewed by the science community; and
6. inspire students and the public.

By conducting these activities, such a U.S. base operated by NASA would establish and expand a U.S. geopolitical presence in deep space and provide initial support and contracts for private-sector activities of interest to the United States.

I suggest that the U.S. Antarctic Program provides a useful parallel in terms of motivation, activities, and operations. In this article, I review the case for a NASA research base on the Moon and review motivations and operations of the U.S. Antarctic Program and apply them to the case of a NASA lunar base. There is a contrast between the Antarctic bases, which are national bases cooperating in the context of an international treaty, and the ISS, which is a specific joint international effort. I am suggesting that the Antarctic model is more appropriate for a moon base because the Moon—an extended geographical location—is more like the Antarctica than the ISS—a specific location in orbital space. A U.S. base would provide more flexibility for U.S. actions in light of the wide range of private and public activities that might be conducted on the lunar surface in the future than an international base with specified partners.

THE U.S. ANTARCTIC PROGRAM

The United States has operated research bases in Antarctica continuously since the start of the International Geophysical Year in

 DOI: 10.1089/space.2013.0018

1955. The political, programmatic, and operational approach of the U.S. Antarctic Program provides a useful pattern for a NASA research base on the Moon.

The international regime in Antarctica is governed by the Antarctic Treaty,[1] which is sometimes compared with the Outer Space Treaty.[2] Currently, 50 countries are signatories to the Antarctic Treaty, including China, Russia, Germany, Chile, Argentina, Norway, Australia, New Zealand, and the United Kingdom. To participate in the Antarctic Treaty, a nation must demonstrate its interest in Antarctica by conducting substantial scientific research activity there, "such as the establishment of a scientific station or the dispatch of a scientific expedition."[1] The treaty mandates that the focus of national activities is science and prohibits military bases *per se* although most national bases are supported by national military assets. Several countries within the Antarctic Treaty claim areas of Antarctica as territory. Neither the United States, Russia, or China have any territorial claims, nor do they acknowledge the territorial claims of other countries. The treaty suspends these claims for the duration of the treaty. The United States maintains three large research bases: Palmer Station in coastal Antarctica (south of South America); McMurdo Station, the main U.S. base; and Amundsen–Scott Station at the geographical South Pole. McMurdo Station is the operations center for ski-equipped C-130 planes and a fleet of helicopters. This makes the U.S. program the largest and most capable national program in Antarctica and guarantees the United States a strong voice in the Antarctic Treaty, an example of what is now known as "Science Diplomacy."[2]

Programmatically, the U.S. Antarctic Program is located entirely within one division of the National Science Foundation (NSF) and operates under the mandate of a presidential directive.[3] The Antarctic Policy Group, which is a subgroup of the Interagency Working Group on Global Environmental Affairs, provides programmatic direction. The Department of State chairs the Antarctic Policy Group. The Antarctic Policy Group formulates policy guidance for U.S. activities under the Antarctic Treaty. Its members represent the Department of State (chair), the NSF, the Department of Defense, and other agencies as appropriate. Several key provisions of the presidential directive[3] warrant quoting here for their direct relevance to the emerging policy issues for the Moon.

"The United States Antarctic Program shall be maintained at a level providing an active and influential presence in Antarctica designed to support the range of U.S. Antarctic interests."[3] A similar sentence applied to the Moon could well be the preamble to a similar policy directive on the Moon.

"This presence shall include the conduct of scientific activities in major disciplines; year round occupation of the South Pole and two coastal stations; and availability of related necessary logistics support."[3] Here the policy mandates the minimal level of activity that satisfies U.S. interests and defines science activities as the main activity at the Antarctic bases. A moon policy may mandate one or two permanent bases and the conduct of scientific activities.

"Every effort shall be made to manage the program in a manner that maximizes cost effectiveness and return on investment."[3] This is a key aspect of the Antarctic Program. The fiscal year 2012 budget for the U.S. Antarctic Program was approximately \$350 million and includes funds for merit-reviewed grants to scientists as well as logistics support. NSF's budget request for fiscal year 2012 was approximately \$7 billion, making the Antarctic Program ~5% of the agency total. As discussed below, an existential challenge to a NASA research base on the Moon is to keep the operating costs to a similar fraction (<10%) of NASA's total budget.

"[T]he National Science Foundation shall continue to budget for and manage the entire United States national program in Antarctica, including logistic support activities so that the program may be managed as a single package."[3] This unification of organization has been a management success for the U.S. Antarctic Program. The logistics and science programs are within the same organizational unit and therefore do not suffer from bureaucratic competition. As discussed below, this is in marked contrast to the NASA organization, which separates the science to be done on the Moon and the transportation to the Moon into competing offices.

"[U]se commercial support and management facilities where these are determined to be cost effective and will not, in the view of the Group, be detrimental to the national interest."[3] This aspect has proved important in shaping the U.S. Antarctic Program. My personal research involved over 15 seasons in Antarctica from 1980 to 2010, and I can provide scattered evidence that this change to the private sector greatly improved science participant satisfaction. McKay's work, referenced here,[4] is an early look at the 1980s Antarctic program and its relevance for a Mars base. An example of private-sector involvement is helicopter operations at McMurdo Station by a competitively selected private contractor; until the 1990s, helicopter support at McMurdo Station was provided by a U.S. Navy squadron. In the 1980s, McMurdo Station operations were primarily conducted by U.S. Navy personnel; now the station is operated by a competitively selected private contractor (currently, Antarctic Support Contract, a division of Lockheed Martin located in Centennial, CO). The change in the mean age, gender distribution, and, most importantly, motivation, of the station staff is remarkable and healthy—as well as cost-effective.

Current U.S. Antarctic Bases are larger than might be the case for a NASA Research Base on the Moon. In the summer spanning October 2012 to February 2013, the average population of McMurdo was 940 (weekly average) and the total was 2,300. A typical winter population at McMurdo is 180. For the South Pole station, the summer weekly average for 2012–2013 was 150 and the total 450, with a winter population of 45.

For many years, the U.S. Coast Guard provided icebreakers capable of cutting a channel in the sea ice in McMurdo Sound each year, creating a path for ships carrying supplies and fuel for the program. Because of a shortage of U.S. icebreakers, Swedish and Russian icebreakers have been chartered to open the channel. Similar flexibility in procuring core transportation capabilities, including contracting for the services of other nations and private contractors, may be necessary in a U.S. moon program as well.

A unique component of the U.S. Antarctic Program is the fleet of ski-equipped LC-130 Hercules aircrafts that are capable of landing heavy cargo on snow and ice runways. Before 1999, the U.S. Navy operated these planes. Since 1999, the 109th Airlift Wing of the N.Y. Air National Guard has taken over the LC-130 fleet and supports U.S. operations in Antarctica. The LC-130s are a key transportation asset for the U.S. Antarctic Program for transportation of personnel and material from McMurdo to South Pole Station and to inland sites of scientific research. They are also used for search-and-rescue operations in the interior of the continent. Transportation from Christchurch, New Zealand, to McMurdo Station, Antarctica, is provided by both U.S. Air Force C-17 cargo jets and LC-130s. Independent contractors provide light-aircraft and helicopter support for the program.

OTHER RELEVANT ANTARCTIC PROGRAMS

My goal in this article is to propose U.S. government (NASA) moon base activity, and for this purpose, the U.S. Antarctic Program is the most relevant model. Many other nations have Antarctic programs, but, not surprisingly, their programmatic structures reflect national policy and politics. A few examples illustrate this; for instance, in New Zealand, the Ministry of Foreign Affairs and Trade is the government agency responsible for New Zealand's overall interests in Antarctica and the Southern Ocean and is responsible for the operations of New Zealand stations in Antarctica.[5] In Australia, the Antarctic program is a division of the Department of Sustainability, Environment, Water, Population and Communities. In Argentina, the Dirección Nacional del Antártico was a dependency of the Ministry of Defense until 2003, when it became the Dirección Nacional del Antártico and the Instituto Antártico Argentino as part of the Ministry of Foreign Affairs, International Trade and Culture. In Chile, El Instituto Antártico Chileno is part of the Ministro de Relaciones Exteriores de Chile.

It has long been recognized that the isolated and confined Antarctic stations provide a relevant model for studies of human factors for space applications.[6] Two stations, Concordia and Princess Elisabeth, warrant mention in this regard as they have consciously incorporated space applications into their activities.

The joint French-Italian Concordia Research Station was built on the high Antarctic plateau (over 3,000 m elevation and over 1,000 km from the coast) and opened in 2005. The science at Concordia Station includes studies of the many stress issues characteristic of isolation and confinement and comparison with long-duration deep-space missions as a useful analog platform for research relevant to space medicine. Research at Concordia has included studies of chronic hypobaric hypoxia, stress secondary to confinement and isolation, circadian rhythm and sleep disruption, individual and group psychology, telemedicine, and astrobiology. Concordia Station has also been used to conduct studies of human factors related to Mars missions.[7]

The Princess Elisabeth base is another base with interesting space exploration applications. This base is a Belgian scientific polar research station, commissioned in February 2009. The station was designed and built to operate entirely on solar and wind energy and uses waste-water recycling—both of these technologies have applications for future long-duration human missions. The station can accommodate up to 16 personnel at a time.

In addition to the many national programs, there are growing private enterprises in Antarctica. Most focus on tourism using ships to move around the edge of the Antarctic continent. Two of the private operators that work inland warrant mention here because similar private enterprises might develop for transportation and tourism on the Moon.

The Antarctic Logistics Centre International (ALCI) is a private company based in Cape Town, South Africa, and started in 2002. ALCI acts as logistics service provider to national programs, private expeditions, and tourists primarily by providing air service between Cape Town and an ice runway known as the Novo Airbase, not far from the Russian Novolazarevskaya station. The flights operate from late October to the beginning of March and are based on an Iljushin IL-76 four-engine jet that carries ∼20 metric tons of cargo and 80 passengers. The ability to purchase a seat on a commercial service greatly simplifies and reduces costs. U.S. expeditions in the Novolazarevskaya area have made use of the ALCI services allowing access to that region of Antarctica at a fraction of the cost that would be required if the expedition had to do all the logistics from scratch. One could imagine SpaceX or some similar private company providing routine flights to and from the Moon with seats available for purchase by tourists and scientists.

White Desert is a private tour operator that works in conjunction with ALCI. They offer tour packages that range from a 3-day trip to Antarctica to longer exploration-based trips. For example, a typical 8-day trip is priced at 38,400 € (∼$51,000) per person. It is interesting to note that while initially virtually all travelers to Antarctica were once part of national bases or expeditions, this changed in the late 1980s, when tourism began in earnest. Now it has been estimated that over 150,000 tourists visited Antarctica between 2007 and 2010[8]—vastly outnumbering the scientists at all national stations combined. While the number of tourists already exceeds the number of scientists, typically science personnel are in Antarctica for a much longer time than tourists and so are more numerous in terms of person-days in Antarctica. The importance of tourism is recognized by the Antarctic Treaty System. Treaty parties come together once a year at the Antarctic Treaty Consultative Meeting (ATCM). As an invited expert since 1992, the International Association of Antarctica Tour Operators (IAATO) participates in annual ATCMs, providing expert advice on tourism-related issues. In its role as representative for the Antarctic tourism industry, IAATO also submits information papers and contributes to discussions by the Antarctic Treaty party delegates.

There are no settlements in Antarctica similar to the concept of effective colonization on the Moon. There are permanent research bases with rotating crews and temporary research and tourist encampments in Antarctica. While some nations have operated "schools" and claim that residential communities are present, these are devices to bolster national territorial claims only. It is also interesting to note that there has been no commercial-scale mineral extraction on the continent. It has not been practical to extract resource from the continent because of the high operations and transportation cost. This may be the case on the Moon as well—the only activities for the indefinite future will then be science bases and tourism.

TO BOLDLY STAY

The notion of a long-term NASA base on the Moon is not a common theme in the current discussion of future human exploration options. There seems to be an implicit assumption that if we do establish a base on the Moon, it would be a temporary activity lasting perhaps a decade or two at most. Some even argue that NASA should be constantly on the frontier and thus switching from one destination to another would be a feature, not a problem. This is not a useful perspective, and the Moon will be our first chance to show that we know how to stay in space for the long-term. The U.S. Antarctic Program is a relevant analog in this respect, maintaining a continuous research program in Antarctica for the past 55+ years. The commitment to stay in Antarctica is clearly evident in the planning of the program: the new South Pole station (*Fig. 1*) opened in 2005, and it has a design lifetime of 30 years. Fifty years in the past, and thirty years into the future; that is a long-term research program we can use as a model for the Moon and Mars.

The primary reason that even advocates of a lunar base argue for a temporary base is the assumption that a lunar base will take most, if not all, of NASA's budget to operate. Current cost estimates for a lunar base and past experience with large space projects such as the Space Shuttle and the ISS seem to argue strongly against the possibility that the long-term operating costs of a moon base can be reduced to a fraction of NASA's budget. This is the primary challenge for the concept of a long-term NASA research base on the Moon. Indeed, it is an existential challenge. Unless the operation costs of the lunar base are be kept to a fraction of the NASA budget, the base cannot be maintained. Transportation and operations costs will initially be high, but must go down, probably by an order of magnitude. This must be planned from the start. One approach might be to develop cost sharing on the transportation along the ALCI model discussed above for Antarctica.

There are several reasons why the focus here is on a NASA research base. First, NASA needs to learn the lessons of long-term operations on another world, develop and test new tools to enable exploration of more distant worlds, and so on. Second, the Moon is in space and NASA is the federal agency charged with space matters. There is nothing wrong with NASA having a sustained mission. It is not the case that everything NASA does must end after a decade. As discussed above, the U.S. Antarctic Program has benefited from organizational coherence. The organizational model is based on the geography rather than the discipline. Everything in NSF dealing with the Antarctic—science, logistics, safety, environmental impact, and so on—is in one division. NASA could take a similar geographically defined program model for near-earth space (the Moon, Mars, and the near-earth objects), making everything dealing with the science and human exploration of that geographical region a single organization.

Fig. 1. The U.S. South Pole Station.

One of NASA's roles is to support research. It is enough that NASA builds a research base on the Moon to support a 50+-year program of field work. NASA does not need to build a liquid-oxygen "gas station" on the Moon or model its plans on some financial return on investment from lunar mining. Others can play these parts if they prove to be practical—an unlikely prospect in my view. In Antarctica, mining resources has proven impractical and colonization uninteresting. After 50 years there are only research bases in Antarctica, not mining towns or settlements. However, ecotourism is booming. This will almost certainly happen on the Moon as well.

CONCLUSION: FROM THE MOON TO MARS

My personal scientific focus is Mars as well as the two big questions about Mars: Was there life on Mars of a different origin than life on Earth? Can the future Mars be a place where humans live and work, and can it have a global biosphere? To answer these questions, we must establish on Mars a long-term research base and conduct investigations for a generation or two. Once we answer these questions, we will then be in a position to decide what we want to do about Mars and life—possibly the focus of work for many more generations.

It is clear to me that we will not be able to build a long-term research base on Mars if we don't first do it on the Moon. We have to learn engineering lessons, management, and operations lessons; most of all, we have to learn to stay. We have to learn that the Moon and Mars are not places to visit, but they are places, like Antarctica, where we will stay. A permanent lunar base plus deep-space missions with humans and a Mars sample return program are the key steps leading to a permanent base on Mars.

As a start, we can plan for 50 years on the Moon. There is plenty of scientific research to be done. After 50 years in Antarctica, there is no shortage of science projects proposed each year, and the Moon is at least as interesting as the continent of Antarctica. Indeed, the Moon is a natural world with natural complexities waiting to be discovered. The type of science to be done on the Moon is fundamentally field science. This makes it very different from the Space Station, which is a constructed laboratory. The difference between field science and laboratory science is key. Laboratory science centers on testing hypotheses, whereas field science centers on discovering nature. Every year, new things will be discovered on the Moon that will raise new questions and spawn new research.

I conclude that we don't need an "exit strategy" for the Moon; we need a "permanence strategy." The key to staying on the Moon and also going on to establish a long-term research base on Mars is driving down the transportation and operations cost of the moon base so that it takes up no more than a portion of NASA's total budget. That is the biggest management and engineering challenge we face as we plan a return to the Moon, this time to stay.

ACKNOWLEDGMENTS

This work was developed when I was the program scientist for the Robotic Lunar Exploration Program and subsequently the deputy program scientist for Constellation. I thank two anonymous reviewers for helpful comments.

AUTHOR DISCLOSURE STATEMENT

No competing financial interests exist.

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