Costs of an International Lunar Base

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Following the celebration of the 40th anniversary of the Apollo 11 moon landing, a presidentially appointed committee is preparing its final report reviewing U.S. plans for future space exploration. In its summary report, the commission has suggested an exploration option that drops the goal of returning to the moon and building a base there, something that has been a centerpiece of U.S. exploration plans for the past five years or more. The suggestion to drop a return to the moon is based in large part on budget projections that forecast just how much and how long it will take the United States to carry out its space exploration plans on its own. These scenarios do not factor in international collaboration. The development of a lunar base has been identified by the Beijing Declaration as the ideal next project for international collaboration on space exploration. CSIS Space Initiatives has made an estimate, based on available literature, that the likely costs of developing such a base would be about $35 billion, and operating the base would run about $7.35 billion per year. By comparison, the development cost for all but the Russian section of the International Space Station (ISS) is estimated at around $85 billion, including $35 billion for Space Shuttle missions. In the years after the Shuttle retires, the annual operation costs of the ISS will be $4.5 billion per year.[1] The estimated operating costs for the lunar base assume no in-situ resource utilization. All supplies (O_2, H_2, food, etc.) would be supplied from Earth and recycled to the maximum extent possible. If useable water ice is found near the base, or oxygen-rich minerals can be utilized, operating costs will decrease significantly.

Development of the Base

Development of the lunar base is estimated at $35 billion for a base that can host a four-person crew and remain unmanned between missions. Our estimates for both development and operation of the lunar base assume that it is located at the south pole. This location offers areas of scientific interest—for example, craters with possible water ice deposits—and quasi-permanent sun exposure, as well as the most conservative assessment for transportation to the lunar surface.[2] The costs do not include development of the heavy-lift Ares V or the Orion crew capsule. Although an Ares V or equivalent will be needed to transfer the lunar base from Earth to the Moon, it is capable of other exploration and scientific missions, including deploying third-generation space telescopes, robotic and human missions to near-Earth objects, as well as missions to the Lagrange Points and eventually to Mars. It will serve as the workhorse for the future exploration of the solar system and beyond. The four-person crew capsule, Orion, is developed for the Moon but will first be used to transport crew to the ISS in replacement of the Space Shuttle. Therefore, Orion development costs are not included in the lunar base project. However, a margin of $2 billion is calculated to account for unforeseen technological and budgetary problems. The development costs of the Altair lander flying aboard the Ares V or an equivalent, estimated to be about $12 billion, are part of the lunar base project. Furthermore, a universal lander, needed to deliver cargo to the lunar base using the medium launchers, has estimated development costs of $2 billion.[3]

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[1] Government Accountability Office, "NASA: Challenges in Completing and Sustaining the International Space Station," GAO-08-581T, April 24, 2008; Government Accounting Office, "Space Station: Actions Under Way to Manage Cost, but Significant Challenges Remain," GAO-02-735, July 17, 2007.

[2] Doug Cooke et al., "Lunar Architecture Update" (paper presented at 3rd Space Exploration Conference, Denver, CO, February 26–28, 2008); Gaspare Maggio et al., "Ensuring an Effective, Safe, Reliable, and Affordable Architecture for Earth to Lunar Space Transportation" (paper presented at 1st Space Exploration Conference, Orlando, FL, January 30–February 1, 2005).

[3] A. Charania, "The Trillion Dollar Question: Anatomy of the Vision for Space Exploration Cost" (paper presented at AIAA Space 2005 Conference, Long Beach, CA, August 30–September1, 2005); Todd J. Mosher and Jeffrey Kwong, "Returning to the Moon at a Modest Cost: The Shackleton Mission" (paper presented at AIAA Space 2004 Conference, San Diego, CA, September 28–30, 2004); Jason Held et al., "Systems of Systems Approach to Modeling Lunar Bases" (paper presented at AIAA SPACE 2008 Conference, San

Although these cost estimates include some margins, NASA projects have typically run 50 percent over budget, according to recent estimates.[4] With a goal of a first landing on the Moon 10 years from now, at the 50th anniversary of Apollo 11, the development costs for the lunar base would average $3.5 billion per year, the equivalent of what is currently spent operating the Shuttle. The lunar base by itself is quite affordable; however, significant funding will also be needed during this time for the transformation to a post-Shuttle launch system and utilization of the ISS until 2020.[5]

Operating Costs

Operating costs for the lunar base are estimated at about $7.35 billion per year, assuming year-round occupancy. Designing the lunar base to be left uninhabited between missions would offer the possibility of fewer or shorter missions and therefore reduced annual costs. In support of the lunar project, there will be three to four international medium-launch systems, for example Ares I, Ariane 5, Delta IV Heavy, Long March 5, and the H-IIC.[6] These launchers will be interoperable to launch cargo to the lunar south pole and a four-person Orion capsule to low Earth orbit. Once in orbit, that capsule will meet up with the Earth Departure Stage and Altair lunar lander, which are launched by Ares V or an equivalent. Operating costs are based on two four-person crew rotations per year.[7] The two Orion launches are estimated at $0.6 billion per year, with the corresponding Ares V launches costing $2 billion per year. Cargo needs are estimated at 17.6 metric tons (mt) per year—that is, 2.2 mt of supplies per person for a 180-day mission.[8] An estimated 15 cargo launches (1.2 mt of cargo with a 0.5-mt lander) will be needed per year, at an annual cost of $3.75 billion.[9]

Table 1. Development Costs

Altair lander	$12 billion
Universal lander module	$2 billion
Lunar base (habitation and support modules)	$17 billion
2 Ares V launches for base modules	$2 billion
Orion safety margin	$2 billion
Total	**$35 billion**

Table 2. Annual Operating Costs

2 Ares V launches with 2 Altair landers	$2 billion
2 Ares I (or equivalent) and Orion launches	$0.6 billion
15 medium launches with universal cargo lander	$3.75 billion
Support services and equipment	$1 billion
Total	**$7.35 billion**

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Diego, CA, September 9–11, 2008); NASA, *NASA's Exploration Systems Architecture Study*, NASA-TM-2005-214062 (Washington, D.C., NASA, 2005); NASA and ESA, "The NASA-ESA Comparative Architecture Assessment, 2008.

[4] Congressional Budget Office (CBO), "The Budgetary Implications of NASA's Current Plans for Space Exploration," April 2009.

[5] NASA FY2005–2010 budget estimates, see http://www.nasa.gov/news/budget.

[6] CBO, "Alternatives for Future U.S. Space-Launch Capabilities," October 2006.

[7] NASA, ESMD Lunar Surface Systems Concepts Studies, June 6, 2008.

[8] Wilfried K. Hofstetter et al., "Analysis of Human Lunar Outpost Strategies and Architectures" (paper presented at AIAA SPACE 2007 Conference, Long Beach, CA, September 18–20, 2007).

[9] NASA and ESA, "The NASA-ESA Comparative Architecture Assessment."