Chapter 7

Costs of the Mission From Planet Earth

As a proposed new program with significant long-term costs, the Space Exploration Initiative (SEI), or Mission from Planet Earth, will come under careful scrutiny by Congress. Estimates by the National Aeronautics and Space Administration (NASA) and the aerospace industry suggest that the total expenditure over a 30- or 35-year period for establishing a lunar base and mounting a crewed Mars mission, including robotics missions, could reach a range of $300[1] to $550 billion[2] (1991 dollars), which would make it the most costly program in NASA's history.[3]

However, at this early stage in the long process of planning the components of a Mission from Planet Earth, which could include a variety of optional paths,[4] any estimates of costs are necessarily extremely uncertain. As the Committee on Human Exploration of Space of the National Research Council pointed out, they "are likely to remain so for some time."[5] Costs depend critically on the range and scale of planned activities, their schedule, and on a multitude of other factors—some well known, some only dimly perceived, and some as yet totally unrecognized. The ability to predict costs will therefore depend heavily on new information developed in the course of the program. Cost estimates also depend on the projected costs of developing new technologies and manufacturing the systems critical to the success of the various projects within the overall plan.

At this early stage of planning for a Mission from Planet Earth, when the many program options available are still under discussion,[6] few of the systems have been defined well enough to estimate costs, even loosely. The models used to estimate costs are notoriously unreliable in projecting the costs of systems incorporating new technologies because the models depend on past development experience. The more familiar designers are with the technology, the more accurate are the cost estimates.[7] For example, NASA and the Department of Energy may wish to pursue development of nuclear energy as the propulsion mode for transporting humans from Earth orbit to Mars, because, if successful, nuclear propulsion could dramatically reduce the transit time between the two planets. Yet the probable costs for developing nuclear propulsion are very poorly known because the development process, contains a significant number of unknown costs. The costs of an interplanetary vehicle powered by nuclear propulsion are also poorly known. Detailed design studies could reduce the cost uncertainties, but only marginally, until additional technology development is done.

If, after pursuing development of nuclear propulsion technologies, the total development costs seem too great, NASA might decide instead to use chemical propulsion, which is much better known, to transport people to Mars, even though the journey could take much longer. Yet the costs

1 Over 30 Years, General Dynamics Space Systems Division, "Lunar/Mars Initiative Program Options–A General Dynamics Perspective," Briefing Report, March 1990.

2 Unpublished estimates developed by NASA for its study entitled, *Report of the 90-Day Study on Human Exploration of the Moon and Mars* (Washington, DC: NASA, November 1989). This estimate, which was for a 35-year period beginning in 1991, includes a 55-percent reserve, and would fund a permanent lunar base and robust human exploration of Mars.

3 By comparison, the Apollo program cost about $116 billion in 1991 dollars.

4 NASA, *Report of the 90-Day Study on Human Exploration of the Moon and Mars* (Washington, DC: NASA, November 1989); Synthesis Group, America at the Threshold (Washington, DC: the White House, June 1991).

5 National Research Council, Committee on Human Exploration of Space, *Human Exploration of Space: A Review of NASA 90-Day Study and Alternatives* (Washington, DC: National Academy Press, 1990), p. 31.

6 See, e.g., Synthesis Group, op. cit., footnote 4.

7 U.S. Congress, Office of Technology Assessment, Reducing *Launch Operations Costs: New Technologies and Practices*, OTA-TM-ISC-28 (Washington, DC: U.S. Government Printing Office, September 1988), app. A.

of an interplanetary vehicle propelled by chemical fuel are also uncertain. Nearly every system in an exploration program faces similar development choices and uncertainties.

Further, in a large project, the development of new technologies is interlinked. New technologies are not "in place" until they are integrated into the rest of the system. Unexpected delays in developing and testing a new launch system, for example, would delay an entire project, even if other technologies were ready. Problems even with supporting technologies and systems may nevertheless delay the project. For example, many payloads designed for launch on the space shuttle had to wait for several years to be launched after the loss of ***Challenger,*** because to redesign and alter them for launch on expendable launch vehicles would have entailed substantial extra cost.[8] Hence, it is far too early to judge the total costs of exploratory missions to Mars using either robotics spacecraft or human explorers.

As NASA develops alternative plans for a Mission from Planet Earth, it should examine carefully which technologies would lead to lower overall costs (including development, manufacturing, and operational costs). Some technologies, e.g., those for space transportation, could have broad application in the space program, and would therefore contribute to overall development of U.S. efforts in space. Others, e.g., space nuclear power and nuclear propulsion, would assist in a drive to expand the human presence beyond Earth orbit, but would have less application elsewhere.

COST ISSUES

Comparing Robotic and Crew-Carrying Costs

Because of the large uncertainties in making cost estimates for the Mission from Planet Earth, comparisons between a set of robotic missions and human missions are also highly uncertain. However, experience with previous space projects provides some guidance. Several OTA workshop participants estimated that, based on their experience with developing and managing various space projects, specific robotic exploration projects might cost one-tenth to one-hundredth as much as human exploration.

These differences are the result of greater weight for human missions, the need for life-sustaining systems, and the need to provide for crew safety. However, comparisons between the costs of carrying out missions using only robots and the costs of crew-carrying missions can be deceiving because the two kinds of enterprises would often accomplish different objectives.

The overall mission strategy would also have a major effect on the costs of either robotic or crew-carrying missions. For a Mars mission, it would, for example, depend on whether human crews would expect to work and live largely in habitats on the Martian surface while sending robotic rovers out to explore, whether crews would themselves do most of the exploring, or whether they would remain in orbit about the planet controlling rovers on the surface.

It is possible at this stage to reach very limited conclusions about total costs of both robotics and human exploration by examining several major systems that would be required as elements of the overall architecture of a Mission from Planet Earth. Figure 3-1 in Chapter 3 presents technologies in eight categories that may be needed to mount robotics exploratory ventures, develop a permanently occupied lunar base, and send a human crew to Mars. This figure reveals two major conclusions. First, human exploration of the Moon and Mars would necessitate development of some nine new critical technologies, each one of which could cost several billion dollars to develop. For example, the development and testing of a new Earth-to-orbit space transportation system (the National Launch System) could cost

8It cost between $3o and $4o million t. reconfigure the Cosmic Background Explorer (COBE) satellite for launch on an expendable launcher after *Challenger* was lost.

about $11 billion (1988 dollars), including facilities.[9] Second, robotics missions would require far fewer expensive new technologies and systems. With the possible exception of aerobraking[10] for a Mars mission,[11] robotics exploration (sample return mission) would require the development of few major new technologies beyond automation and robotics (A&R) technologies, though several listed would clearly increase the chances of successful completion of certain scientific missions, and others would provide considerable leverage in accomplishing some science objectives.

In attempting to understand cost comparisons between missions that would use robotic technologies on the Moon or Mars and those that would use crews, Congress could ask NASA to present the costs ***and cost uncertainties***[12] as well as the benefits and drawbacks of various alternatives. Congress could then decide whether the estimated costs justified expending tax dollars.

Schedule

Each project carries with it an optimal timetable for completion that results in minimum costs. Trying to push technology and organizations too fast results in higher total costs. Stretching out the schedule or delaying it once started also result in higher costs. Because the risks of incurring higher than optimal costs increases with the size of the project, the Nation might be well advised to break up the Mission from Planet Earth into a series of relatively small projects,[13] each with its own objectives and schedules. Such a strategy should make budgeting easier and reduce the risk that any one project would suffer being delayed, especially given the extremely long timescale for the Mission from Planet Earth. However, under these circumstances, the overall plan would have to be extremely flexible to account for unexpected successes or delays. If everything works out, a fully integrated approach is much less costly than a flexible one. But a flexible approach allows plans to change as budgets and national priorities change over time.

As noted earlier, the OTA workshop concluded that the scientific objectives for exploring the Moon and Mars could be pursued on a wide variety of timetables, depending on the availability of technology and funding, and scientific progress. Launch opportunities for Mars occur about once every 2 years. Launches to the Moon can be carried out several times a month. Hence, scientific missions can be planned and executed as new information indicates new questions to ask. However, political or other objectives may suggest a particular timetable, such as the date of 2019 that the Bush administration has proposed for landing a crew on Mars, which is 50 years after the first Apollo landing. Given a timetable, planners can produce an overall system architecture to fit within it.[14] An architecture based on political considerations may not accomplish the full range of possible scientific objectives, in part because planners experience considerable temptation to cut scientific objectives in order to meet a predetermined schedule, especially when stretching the schedule would result in higher overall costs.

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[9] Manufacturing and operations costs would be at least $70 million per copy (1988 dollars). U.S. Congress, Office of Technology Assessment, *Access to Space: The Future of the U.S. Space Transportation System,* OTA-ISC-415 (Washington, DC: U.S. Government Printing Office, 1990), p. 36.

[10] Aerobraking makes use of the Martian atmosphere to slow down an interplanetary vehicle to the point that it can be captured by Mars' gravitational field. A very massive interplanetary vehicle would either have to usaerobraking or cany sufficient fuel to slow it for capture by Mars.

[11] Figure 3-1 lists aerobraking as a critical technology for returning samples from the surface of Mars. However, the strength of its importance for such a mission depends directly on how the mission is carried out. A robotics rover mission using small rovers would not necessarily need aerobraking. Such a mission could be accomplished with existing technology.

[12] The amount of cost uncertainty provides a measure of the cost risk involved.

[13] Planetary projects, by their nature, tend to be rather large and take several years to plan and complete. Delays in major subsystems or in supporting systems, e.g., space transportation, can introduce substantial delays in such projects. Nevertheless, it may be more cost-effective in the long run for project leaders to resist the temptation to load many different objectives onto a single project.

[14] See, e.g., the system architectures examined in the Synthesis Group, *America at the Threshold* (Washington, DC: The White House, June *1991).*

Operational Costs

The operational costs for exploration, whether robotic or human, could be very high. Such costs are notoriously hard to judge, as they depend heavily on the success engineers have in developing systems that require relatively little continuing oversight. For example, when the space shuttle was under development, planners expected operational costs to be high in the initial operational stages, but to decrease steadily as operators gained experience with its many subsystems.[15] @cl. time, yearly operational costs of the shuttle have actually increased[16] and NASA has been unable to decrease the per-flight operational cost by increasing the flight rate.[17] In part, the wide disparity between expectations and reality in operational costs results from the fact that when budgets became tight as the shuttle was under development, items that would have reduced long-term operational costs, but required near-term development, were often cut from the shuttle budget. The result was a series of near-term reductions at the expense of long-term continuing costs.[18] For systems designed to support humans, safety considerations lead to numerous design improvements *after* a system has been built, which also increases costs.

As planning for the Mission from Planet Earth proceeds, it will be important for planners to examine carefully the operational costs of each project within the overall plan, including robotic ones, and determine whether operational costs can be reduced. By reducing the number of personnel required, A&~ technologies could be used to control costs. In the Shuttle program, for example, the large number of contractors and NASA employees required to refurbish and launch each orbiter, and to follow the missions while in progress, is a major contributor to overall mission costs.[19]

Reducing Costs

As noted, costs will also depend on new technologies that might be developed during the program. Actual costs could be higher or lower depending on the technological hurdles encountered and the cost reducing effects of technological and management innovations. Many of the A&R technologies being developed to reduce manufacturing costs on aircraft assembly lines, or to reduce the costs of launch vehicles, may have particular utility for the Mission from Planet Earth.[20]

The proposed Mars sample return mission provides an illustrative example. Early studies suggested that the costs of sending spacecraft to Mars to return a sample to Earth might reach about $10 to $15 billion.[21] Yet recent studies suggest that miniaturized robots and simplified objectives might make it possible to mount a more limited sample return mission for much less cost.[22] For example, small robots could be launched on Delta or Atlas launch vehicles, which are available today from commercial launch service companies. Because many small robots could be sent to several different locations and landed using existing technology, they could potentially sample wider regions than a single rover collecting samples from the surface. Even if several small rovers were to fail, the remaining ones would still carry out their missions, reducing

[15] Advisory Committee on the Future of the U.S. Space Program, *Report of the Advisory Committee on the Future of the U.S. Space Program* (Washington, DC: U.S. Government Printing Office, December 1990).

[16] NASA outlays for space shuttle operations have increased about 17 percent per year since 1988. Projected outlays for fiscal Year 1991 equal $2.79 billion.

[17] U.S. Congress, Office of Technology Assessment, Reducing *Launch Operations Costs: New Technologies and Practices,* OTA-TM-ISC-28 (Washington, DC: U.S. Government Printing Office, September 1988).

[18] Ibid., pp. 5-6.

[19] Ibid., p. 40.

[20] Ibid., p. 4.

[21] "Mars Rover Sample Return, Technical Review, Final Report, vol. 5," Jet Propulsion Laboratory, Sept. 22, 1988.

[22] David P. Miller, "Mini-Rovers for Mars Exploration," *Proceedings of the Vision-21 Symposium,* Cleveland, OH, April 1990.

overall mission risk compared to a single rover/ sample return mission. Yet, small robots may not be able to carry the computing capacity necessary to do intricate tasks,[23] or tasks requiring the use of heavy equipment.

In attempting to reduce costs, the overall management approach may assume as much or more importance as the technologies used. For example, project managers of the Strategic Defense Initiative Organization Delta 180 Project found that "decreasing the burden of oversight and review, and delegating authority to those closest to the technical problems, resulted in meeting a tight launch schedule and reducing overall costs."[24] Determining whether these or similar techniques are appropriate to reducing costs in a high-cost, high-risk robotic or crew-carrying mission would require careful study. However, experience with earlier planetary projects suggests the following maxims for project development:[25] 1) keep the entire project as simple as possible; 2) do as much testing as possible before launch; 3) provide adequate funding reserves for unforeseen problems; 4) avoid complex software and complex internal processes; and 5) keep science payloads to the requirements.

PAYING FOR THE MISSION FROM PLANET EARTH

Returning crews to the Moon and exploring Mars would have a major impact on NASA's yearly budget, and could adversely affect the funding of NASA's other activities. To support the Missions to and from Planet Earth, and the various programs to which NASA has already committed, the Report of the Advisory Committee on the Future of the U.S. Space Program recommended 10-percent real growth in NASA's overall budget over a period sufficient to pay for the Mission from Planet Earth as well as other NASA activities.[2] The National Research Council Committee on Human Exploration of Space recommended growth of NASA's budget by a "few l0ths of percent in GNR"[27] During the years of highest spending on the Apollo program (1%4-66) NASA spent about 0.8 percent of the GNP.[28] However, the United States was then in the middle of a "race to the Moon," and beating the Soviet Union to it was a national priority. No such race exists today.

Significant pressures on the discretionary portion of the Federal budget will make obtaining a real growth rate in NASA's budget of 10 percent, or increases of a few tenths percent of the GNP, extremely difficult, unless our national priorities change.[29] NASA's budget submission for fiscal year 1991 included a total of $%2.8 million for activities cited in the budget summary as related to SEI. Of that amount, about $188 million was targeted to support new activities.[30] In passing the Appropriations Bill for the Department of Housing and Urban Development and Independent Agencies,[31] Congress deferred consideration of the proposed SEI as a result of "severe budgetary constraints which limit the agency's ability to maintain previously authorized projects

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23 Computing capacity per weight and volume has decreased dramatically over the last 30 years. If existing trends continue, computing capacity may not be a limiting factor.

24 U.S. Congress, Office of Technology Assessment, *Reducing Launch Operations Costs: New Technologies and Practices*, OTA-TM-ISC-28 (Washington, DC: U.S. Government Printing Office, September 1988), p. 14.

25 Scott Hubbard, Jet Propulsion Laboratory, personal communication, 1991.

26 Advisory Committee on the Future of the U.S. Space Program, op. Cit., footnote 15, p. 4.

27 In 1990, NASA's budget was about 0.18 percent of the GNP.

28 National Research Council, Committee on Human Exploration Of Space, op. cit., footnote 5, p. 31.

29 David Moore, Statement before the Committee on Space, Science, and Technology, U.S. House of Representatives, Jan. 31, 1991.

30 For fiscal year 1991, NASA placed other ongoing activities in the SEI category to demonstrate that many of its existing activities were already directed toward the goals of SEI.

31 H.R. 5158, which became Public Law 101-507.

and activities."[32] NASA received about $584 million. NASA's budget submission for 1992 contains $94 million in support of identified SEI activities.

In funding the many elements of the Mission from Planet Earth, or SEI, it will be important to maintain a balance of activities in space. Since the Apollo days, NASA's projects devoted to "manned" activities have received the lion's share of NASA's budget. Recently, that share has increased. In fiscal year 1990, for example, activities for people in space consumed about 70 percent of NASA's budget.[33] Space scientists and other observers of the U.S. space program have raised the concern that the SEI might increase the proportion of funding applied to human activities in space to the detriment of space science, the Mission to Planet Earth and other NASA space projects.[34]

Both the National Research Council's Committee on Human Exploration of Space[35] and the Advisory Committee on the Future of the U.S. Space Program[36] have recommended fencing funding for the rest of NASA's activities from funding for a Mission from Planet Earth. The Advisory Committee specifically recommends "that the civil space science program should have first priority for NASA resources, and continue to be funded at approximately the same percentage of the NASA budget as at present (about 20 percent)."[37] However, the administration and Congress may find it difficult to maintain funding for NASA's base programs if the funding for SEI leads to an even larger percentage of NASA's budget than its endeavors to support people in space now command. Schedule and other delays in such activities would necessarily lead to cost overruns that could "squeeze out" funding for other civilian space activities.

32 U.S. House of Representatives, *Conference Report to Accompany H.R. 5158,* Oct. 18, 1990, p. 44. The report went on to say, "It is inevitable in the conduct of the Nation's civil space program that such human exploration of our solar system is inevitable."

33 Up from about 65 percent in the 2 previous years. U.S. Congress, Office of Technology Assessment, *Access to Space: The Future of the U.S. Space Transportation System,* OTA-ISC-415 (Washington, DC: U.S. Government Printing Office, 1990), p. 5.

34 Robert L. Park, "After 30 Years of Dreams, a Wake-Up Call for NASA," *The Scientist,* May 27, 1991, pp. 11, 13.

35 "The committee believes that it is important for the funding support for HEI [SEI] and other major initiatives to continue to be distinct from that for the remainder of the NASA budget, to avoid eroding the base of other essential space and aeronautical capabilities." National Research Council, Committee on Human Exploration of Space, *Human Exploration of Space: A Review of NASA 90-Day Study and Alternatives* (Washington, DC: National Academy Press, 1990), p. 32.

36 Advisory Committee on the Future of the U.S. Space Program, op. cit., footnote 15.

37 Ibid., p. 25.