# HUMAN EXPLORATION MISSION STUDIES

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## Summary

The nation's efforts "to expand human presence and activity beyond Earth orbit into the solar system" was given renewed emphasis in January 1988, when the Presidential Directive on National Space Policy was signed into effect. The expansion of human presence into the solar system has particular significance in that it defines long-range goals for NASA's future missions. To embark and achieve such ambitious ventures is a significant undertaking, particularly when compared with past space activities.

## Introduction

Two major efforts recently released, the National Commission on Space Report, "Pioneering the Space Frontier", 1986, and astronaut Dr Sally Ride's task force report, "Leadership and America's Future in Space", 1987, have helped set goals and give focus to NASA's future direction. Dr. Ride's task force formulated a plan to achieve the Commission's proposed agenda for the civilian space program. The task force recommended four initiatives:

(i) Mission Planet Earth;
(ii) Exploration of the Solar System;
(iii) Outpost on the Moon;
(iv) Humans to Mars.

The first two initiatives, to a great degree, are being pursued by NASA's Office of Space Science and Applications. However, the last two initiatives prompted the task force to recommend that a special NASA office be established to coordinate and lead human exploration studies. The Office of Exploration was therefore established to provide a focal point for these activities. These include establishing a mature understanding of mission options and opportunities and defining those near-term activities that can provide the greatest impact on future missions.

The Office of Exploration has established a process whereby all NASA field centers and other NASA Headquarters offices participate in the formulation and analysis of a wide range of mission strategies. These strategies were manifested into specific scenarios or candidate case studies. The case

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studies provided a systematic approach into analyzing each mission element. First, each case study must address several major themes and rationale including: national pride and international prestige, advancement of scientific knowledge, a catalyst for technology, economic benefits, space enterprise, international cooperation, education, and excellence. Second, the set of candidate case studies is formulated to encompass the technology requirement limits in the life sciences, launch capabilities, space transfer, automation and robotics, in-space operations, power, and propulsion.

The first set of reference case studies identifies three major strategies: (i) human expeditions, (ii) science outposts, and (iii) evolutionary expansion. During the past year, four case studies were examined to explore these strategies. The expeditionary missions include the Human Expedition to Phobos and Human Expedition to Mars case studies. The Lunar Observatory and Lunar Outpost to Early Mars Evolution case studies examined the latter two strategies. This set of case studies established the framework to perform detailed mission analysis and system engineering to define a host of concepts and requirements for various space systems and advanced technologies. This paper describes the details of each mission and, specifically, the results affecting the advanced technologies required to accomplish each mission scenario.

## Mission studies

The Office of Exploration has established a process whereby reference case studies are examined yearly. This allows for a reasonable subset of options to be studied in some detail in order to establish first order effects and trends in various system elements. Once the study has been characterized in sufficient depth, different system elements can be replaced with new options so that the overall system performance sensitivities can be analyzed. The broad scope in case studies is engineered to provide a wide range of mission options and to avoid making priorities between exploring the Moon or Mars.

The following candidate case studies are the first set of options studied in 1988. These options are not the final set; in fact, during the coming years these cases may be refined and new cases added to form a comprehensive set of options, so that qualified engineering decisions can be made in the final selection process for those studies that will be carried forward into a program phase A/B.

## Human expedition to Phobos

A manned expedition to Phobos, the inner Martian moon, would establish an early U.S. exploration leadership. Activities such as exploration, resource survey, and science station set up would be conducted. Also, a fleet of small, teleoperated "low-tech" rovers could provide enhanced exploration of the Martian surface. The expedition to Phobos satisfies two objectives, those of human exploration, and previously studied robotic missions with sample return options.

Past spectral analysis of both Phobos and Deimos suggest that materials are present that could justify leveraging rocket propellants for future return trips from Mars. Propellant production plants could allow vehicles to carry fuel only for the trans Earth–Mars leg, and refuel at Phobos or Deimos for the trans Mars–Earth leg. Earth to orbit (ETO) mass could be significantly reduced, particularly with an evolutionary Mars mission. The Phobos mission also relieves the pressure on the launch transportation systems because of reduced propellant mass required by not landing on Mars itself.

*Mission scenario*

The Phobos expedition employs a "split/sprint" transportation scheme whereby a cargo vehicle carrying science equipment, crew return propellant, and Mars rovers would be launched on a minimum energy trajectory. About 10 months later, the vehicle carrying a crew of four on a high-energy sprint class trajectory is launched. Nine months later the crew vehicle mates with the cargo vehicle in Mars orbit. Two crew members then board an excursion vehicle and conduct the mission objectives on Phobos. The two remaining crew members teleoperate rovers on the Martian surface and transfer propellant from the cargo vehicle. After about 30 days in the Mars system the four crew members return to Earth having been away from Earth a total of 14 months.

## Human expedition to Mars

Since the invention of the telescope, Mars, with its observed global dust storms and "canali", has been a favorite destination for planetary exploration and colonization. Mars has been called Earth's sister planet because of their similarities, although it is not a very hospitable planet for humans. Scientists have speculated that Mars had more of Earth's characteristics, denser atmosphere, water, for example, which could have supported lifeforms early in its evolution. Thus, there is a large international segment of the population that suggests we return to explore Mars with manned missions.

*Mission scenario*

The Mars Expedition calls for three separate segments launched on successive opportunities. The first segment includes a cargo vehicle preceding the eight member crew on a split/sprint approach as in the Phobos mission. However, the cargo vehicle that transports rovers, surface habitats, and exploration and science equipment is placed in Mars orbit. After spacecraft rendezvous, four crew members descend to the surface in the landing craft for a 20 day stay. The exploration party will perform science experiments and possibly explore the surface for water, minerals, volatiles, and biological traces of present and past lifeforms. The crew will live in the pre-landed habitats and utilize the rover for extended exploration. The remaining crew members in orbit will transfer propellant from the cargo vehicle, perform orbital science and support surface operations. The surface crew will unite with the orbit craft and return to Earth. The total length of the mission would span about 14 months. On ensuing trips, exploration of Phobos and Deimos would also be included in the scenario along with different landing sites on Mars.

## Lunar observatory

The Lunar Observatory, comprised of optical telescope arrays, stellar monitoring telescopes, and radio telescopes would encompass both the radio and optical spectrums. An observatory, constructed on the far or backside of the Moon, could provide scientists with information orders of magnitude greater than could be achieved from one in earth or in low-Earth-orbit. Significant benefits of lunar locations are: circumventing Earth's atmospheric impediments, shielding of electromagnetic waves, and providing a stable foundation for large instruments and arrays.

*Mission scenario*

An estimated four flights to the Moon's far side would be required to emplace the observatory. Two launches a year, one cargo and one crew, make up the mission set. One combined crew/cargo flight per year would follow. The crew of four would remain on the Moon's surface only during the Lunar day using their lander vehicle as a habitat, similar to the Apollo missions. A permanent base is not required because of the short stay periods for maintaining the observatory about every 3 years, and other exploration missions would land at different sites.

Unpressurized rovers would be used as crew transports during the observatory set up and maintenance, as well as automated machinery used for material handling and scientific equipment transport.

## Lunar outpost to early Mars evolution

An evolutionary approach to space exploration is that of building on the experience of living and working on the Moon. The Moon is very attractive to accomplish this, since the transfer time back to Earth is only several days should an emergency situation occur. A sustained human presence on the lunar surface would provide valuable data on working in reduced gravity, human factors considerations with long duration planetary missions, and learning how to extract and utilize local resources.

A recommendation of the National Commission on Space (NCOS) was that a "bridge between worlds" be built, with the first step to develop the

Moon then continue on to Mars. This case study defines the methodology necessary to achieve that goal by building a space exploration infrastructure that would lead to nearly self-sufficient space habitation. This, the most complex and ambitious scenario, stretches the limits of technological advances in space construction, utilization of indigenous resources, life support, artificial gravity, chemical and electric propulsion, aerocapture, material and propellant production, and space power.

*Mission scenario*

A series of both piloted and cargo flights would embark for the Moon. Cargo would be sent on longer transfer trajectories using electric propulsion, and crews sent on fast, chemically-propelled transfer vehicles. It could take several years fully to construct a surface facility, possibly with construction expedited by vehicles operated from Earth. The principle goal of the base is to produce materials and liquid oxygen used for Mars flights. The effort to produce these products is leverage against the mass otherwise launched from Earth.

Sometimes later, possibly 6 - 10 years, the Mars flights would begin once capabilities were sufficient for the successful Mars trip. First, an electric cargo vehicle would transport surface equipment, communications orbiters, rovers, Mars–Phobos transfer vehicles, scientific experiments, and a Phobos propellant plant. As the vehicle approaches Mars, it will deploy aerosynchronous communication orbiters and robotic equipment to Deimos, and a fuel processing plant to Phobos. The plant would produce fuel for future crew return flights.

During the next Earth–Mars launch opportunity, the lunar electric cargo vehicle will be reused to transfer the crew's transport vehicle to lunar orbit for lunar derived oxygen fueling. The cargo/crew vehicle returns to Earth orbit and separates. The cargo vehicle stays in orbit for use as the next ferry trip to the Moon and the crew transport is boarded by the Mars crew. After a systems checkout, they begin their 8 month journey. Several options exist as to Mars stay times: 60 days, 1 year, and 2 years. Continued flights to Mars could occur every Earth–Mars opportunity which is about 26 months apart.

## Mission technology requirements

As the case studies become more mature and focussed, better defined requirements will emerge. However, the preliminary analysis of the 1988 case studies has surfaced many technology areas needing further development. These major areas include the following: surface exploration systems, fluid management, propulsion, automation and robotics in-space operations, aerocapture and power. Table 1 illustrates key technologies as evaluated in relation to the four case studies. Programs such as Pathfinder and the Civil Space Technology Initiative are planned to advance certain technologies that

TABLE 1

Assessment of prerequisite technology

| Critical technology | Human expedition to Phobos | Human expedition to Mars | Lunar observ. | Lunar outpost to early Mars evolution |
|---|---|---|---|---|
| Cryogenic fluid management | ○ | ● | ○ | ● |
| Automated rendezvous and docking | ● | ● | ● | ● |
| Autonomous rovers | | ● | | ● |
| Mars and Earth aerocapture | ○ | ○ | ○ | ○ |
| On-orbit assembly & construction | | ○ | ○ | ● |
| Surface extra vehicular activity suits | | ● | ● | ● |
| Surface power (including SP-100) | | ○ | ○ | ○ |
| Advanced chemical propulsion | ○ | ○ | ○ | ○ |
| Nuclear electric propulsion | | | | ○ |
| *In situ* propellant production | | | | ○ |
| Advanced life support | ● | ● | | ○ |

Legend: ○, indicates required technology; ●, indicates critical pacing element.

TABLE 2

Estimated extraterrestrial power requirements of significant system elements

| System element | Power (kW) | Comment |
|---|---|---|
| Planetary utility vehicle | 1 - 2 | Rechargeable |
| Planetary mining vehicle | 5 - 10 | Rechargeable/peaking |
| Planetary construction vehicle | 15 | Rechargeable/peaking |
| Planetary manned excursion | 30 | Continuous |
| Lunar observatory | 30 - 50 | Full night power |
| Lunar processing | 150 - 300 | Electric/thermal |
| Lunar base | 100 | Crew of eight |
| Mars outpost | 20 | 40 days |
| Mars base | 40 - 50 | 2 years |
| Phobos/Deimos processing | 1000 | |
| Cargo vehicle | 5000 | |
| Staging nodes | TBD | |
| Fuel depot | TBD | |

will provide these programs with mission technology goals. On the other hand, the technologists must predict the degree to which the objective can be met, considering the technological barriers and funding levels, so that the proper estimates can be integrated into the case studies. Significant scenario augmentation, reflecting the change in technology status, may be necessary to accomplish mission objectives.

**Power system requirements**

By design, the case studies span a range of complexity, with the more basic being the Expedition to Phobos, and the more complex the Lunar Outpost to Early Mars. The Lewis Research Center has been chartered by OEXP to perform the power system analyses. These tasks include doing broad trades as well as in-depth investigations. Major study areas include power systems for exploration elements such as: electric cargo vehicles, planetary orbit transportation/staging nodes, mobile equipment resource processing plants, surface science outposts and inhabited bases.

The power levels presented in Table 2 are first cut estimates. As future systems analyses are performed, the values will become more mature. One objective of the power system studies is to discover those technologies that provide the greatest leverage: either by possessing significant mass or reliability advantages, or having a high degree of commonality. Thus, we will be able to focus our resources on those technologies that have the highest pay off.