# Report of the 90-Day Study on Human Exploration of the Moon and Mars

## Cost Summary

November 1989

NASA

National Aeronautics and Space Administration

# Cost Summary

Cost estimates depend on the level of technical definition of the program and the characteristics of the data bases on which the estimate is based. The 30-year time horizon of the Human Exploration Initiative presents a significant cost estimating challenge, since the rapid pace of technological change impacts the historical analogies used for estimating. The cost estimates presented here provide an approximate sizing of the Human Exploration Initiative. Cost estimates for the Initiative are generally consistent with the historical data bases, with no explicit assumption that these future programs will be less costly than their predecessors given the potential impact of technological advances. Program reserves have been included at a level consistent with the overall stage of program definition.

The phasing by fiscal year of the cost estimates provides a representation of the resource levels required. The values for the first several fiscal years represent a reasonably well-defined plan of action. Beyond that point, the estimates assume successful attainment of technology readiness milestones and the achievement of schedules for development programs. The phasing will vary depending upon the changes in major milestones. There are a number of key assumptions which would also alter the phasing, such as the relationship of program requirements with the length of the development phase, externally imposed funding constraints, and any decisions to include explicit schedule margins. Further work is required on the correlation of the cost estimates based on historical data and the schedule assumptions.

# Cost Estimation Methods

For a program with the scope of the Human Exploration Initiative, a variety of cost estimation methods must be employed. Sources of cost estimates included the NASA field installations, the Jet Propulsion Laboratory, and NASA Headquarters. Discrete estimates were developed for technology program augmentations to the Pathfinder program, Civil Space Technology Initiative, and the research base. Historical experience was employed to derive the approximate values for supporting development, systems engineering and integration, program management, recurring operations, new facilities, and civil service staffing levels. Particular attention was given to cost estimates for flight and mission hardware, since these costs either dominate or influence other costs.

Three parametric cost models were used in the process. For many of the major flight hardware elements, two models were employed, estimates were compared, and the estimates judged most credible were included in this analysis. The three models are: the Jet Propulsion Laboratory Project Cost Model, the Johnson Space Center Advanced Mission Cost Model, and the Marshall Space

Flight Center cost model. All of the models use regression equations. The Marshall Space Flight Center model data base consists of subsystem level data collected on historical NASA programs. The subsystem costs are estimated as a function of mass, with a judgmental complexity factor to place the program in the context of the data base. The aggregated subsystem estimates form an estimating base for system level factors, e.g., systems integration, which are used to generate project and program level estimates. The Johnson Space Center data base uses a broader data set, composed of both NASA and non-NASA programs. This model was developed recently, and uses as a key factor for estimating program costs the developing organization's manner of doing business. The Jet Propulsion Laboratory model data base consists of unmanned space programs, and employs estimator knowledge of analogous programs in the estimating process.

These models were applied to the Human Exploration Initiative in the following manner: the Marshall Space Flight Center model was used to generate the estimates for the various space transportation vehicles; the Johnson Space Center model was utilized for all surface systems estimates; and the Jet Propulsion Laboratory model was used for robotic missions and selected other science missions. The confidence level associated with the outputs of this estimating process varies with the level of technical definition. The assignment of reserves to the initial estimate is intended to reduce the uncertainty level. At this point, the costing activity has produced gross program sizing estimates reflecting the pre-conceptual state of technical definition. As the system design concepts mature, the detailed elements will be re-estimated to improve the validity of the estimated funding requirements.

# Reference Costs

The "Report of the 90-Day Study on Human Exploration of the Moon and Mars" describes in detail two principal reference approaches. The costs of these two approaches were estimated over the 1991-2025 horizon in constant fiscal year 1991 dollars. The cost estimates include reserves amounting to approximately 55%, an allowance incorporating both the cost estimating uncertainties for individual developments (i.e., project-level reserves) and allowances for changes in scope (i.e., program-level reserves). Tables 1 and 2 present total program costs for reference approaches A and E divided into key phases: (a) the cost to establish the lunar outpost; (b) the subsequent lunar outpost consolidation and operations costs through 2025; (c) the additive cost to establish the Mars outpost; and (d) the subsequent Mars outpost consolidation and operations costs through 2025.

*Table 1 Reference Approach A*

| | Initial Capability | | Emplacement and Operations | | Totals* |
|---|---|---|---|---|---|
| | $* | FY | $* | FY | |
| Lunar | 100 | 1991-2001 | 208 | 2002-2025 | 308 |
| Mars | 158 | 1991-2016 | 75 | 2017-2025 | 233 |
| Totals | 258 | | 283 | | 541 |

* In Billions, 1991 Dollars

*Table 2 Reference Approach E*

| | Initial Capability | | Emplacement and Operations | | Totals* |
|---|---|---|---|---|---|
| | $* | FY | $* | FY | |
| Lunar | 98 | 1991-2004 | 137 | 2005-2025 | 235 |
| Mars | 160 | 1991-2016 | 76 | 2017-2025 | 236 |
| Totals | 258 | | 213 | | 471 |

* In Billions, 1991 Dollars

The approximate annual phasing of the resource estimates for these two reference approaches is illustrated in Figures 1 and 2. The "NASA base" is consistent with the fiscal year 1991 NASA budget recommendations to the President, exclusive of the Human Exploration Initiative or other future budget program initiatives. The resource phasing estimates have been adjusted to eliminate peaks and valleys produced by summing fiscal year estimates generated by schedule and cost phasing templates overlaid on the parametric model outputs for individual elements.

Overall funding requirements reflect the basic mission strategy: to employ Space Station Freedom as a staging base for the Human Exploration Initiative, to return to the Moon to establish a permanent outpost, and then to send humans to Mars. There will of necessity be variations in the program content, such as the mass carried to low-Earth orbit, the extent of robotic missions, the operational philosophy, the program risk strategy, and the possibility of international participation. In an overarching sense, one of the most significant program

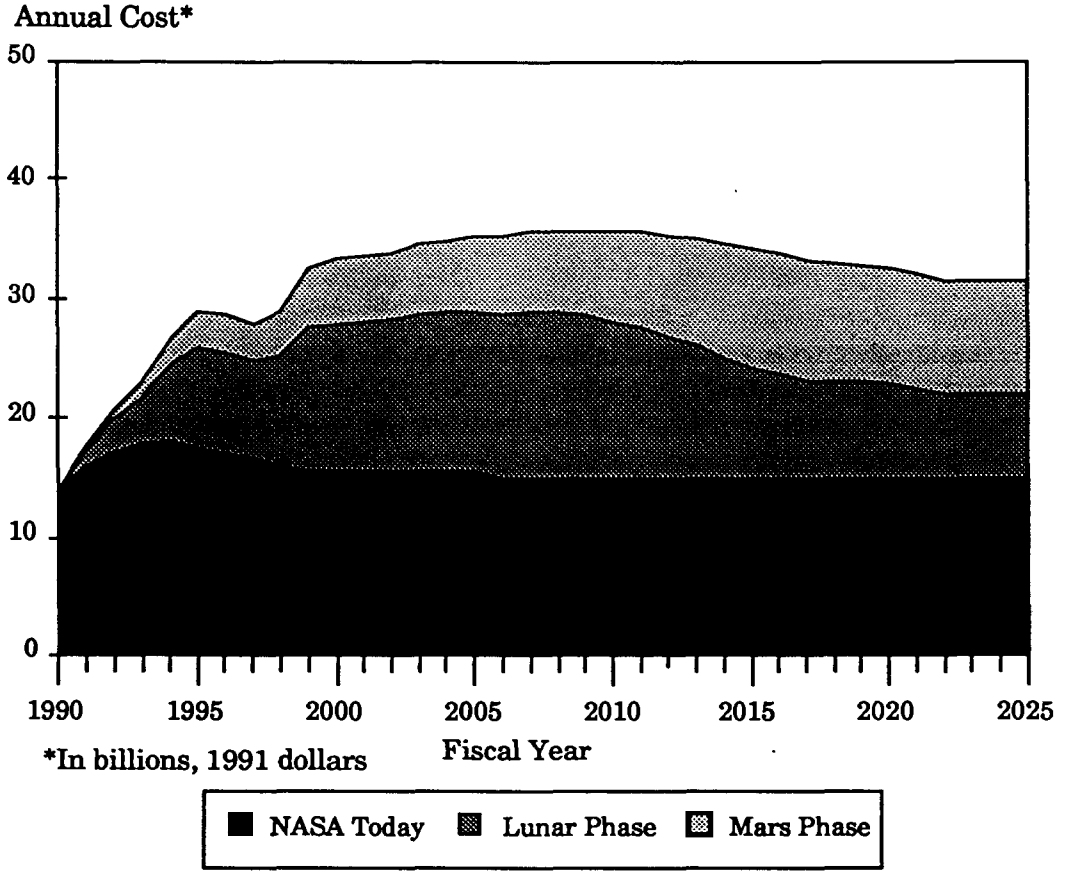


*Figure 1 Reference Approach A*

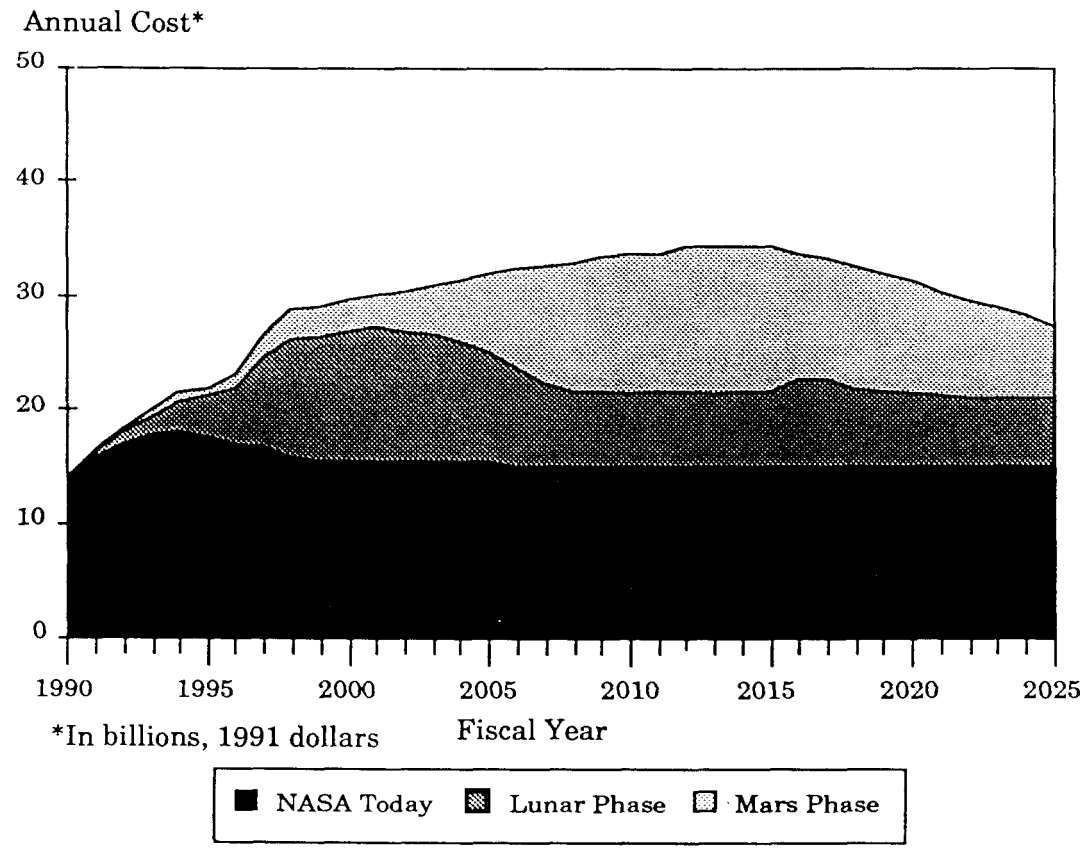


*Figure 2 Reference Approach E*

variations will be the program pace. However, when all of the variables that will have an influence on program requirements are taken into account, the resource demands of the Human Exploration Initiative will be of the magnitude presented here: To build a permanent base on the Moon, approximately $100 billion, and to send humans to explore Mars, approximately $150 billion more, which includes substantial investments for the capability to obtain abundant science returns.