CHAPTER 1.0

# Introduction

The Executive Office of the President established the Review of U.S. Human Spaceflight Plans Committee to develop options "in support of planning for U.S. human spaceflight activities beyond the retirement of the Space Shuttle." The Committee was asked to review the program of record and offer prospective alternatives, not to recommend a specific future course for the human spaceflight program. The Committee consisted of 10 individuals versed in the history, challenges and existing policies and plans for human spaceflight, members representing a broad and diverse set of views on spaceflight's possible future. The Committee's deliberations in its seven public sessions were informed by dozens of briefings, several site visits, and hundreds of documents received directly or through its website.

The current U.S. human spaceflight program appears to be on an unsustainable trajectory. It is perpetuating the perilous practice of pursuing goals that are often admirable, but which do not match available resources. President Kennedy stated, "We choose to . . . do [these] things, not because they are easy, but because they are hard. . ." And, indeed, space operations are among the most complex and demanding activities ever undertaken by humans. It really is rocket science. Space operations become all the more difficult when means do not match aspirations. Such is the case today. The human spaceflight program, in the opinion of this Committee, is at a tipping point where either additional funds must be provided or the exploration program first instituted by President Kennedy must be abandoned at least for the time being.

America continues to enjoy a clear global leadership role in space capabilities. NASA's accomplishments are legion. Foremost among these is the landing of 12 astronauts on the Moon and returning them all safely to Earth. At that time, optimism was such that a study chaired by then-Vice President Agnew provided options to place humans on Mars by the mid-1980s—less than two decades after the initial lunar landing. (See Figure 1-1.)

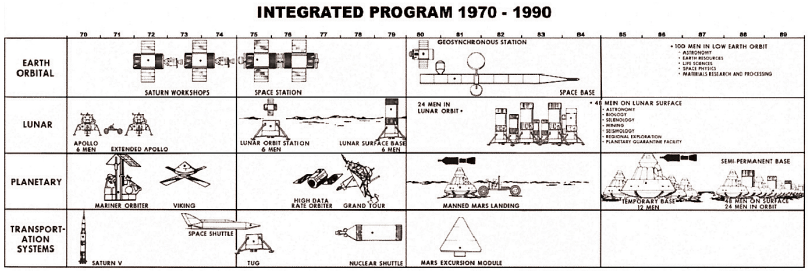


*Figure 1-1.The integrated program that never was. The human spaceflight program that was expected to follow the initial Apollo lunar missions. Only a space shuttle and space station have been developed so far. Source: NASA*





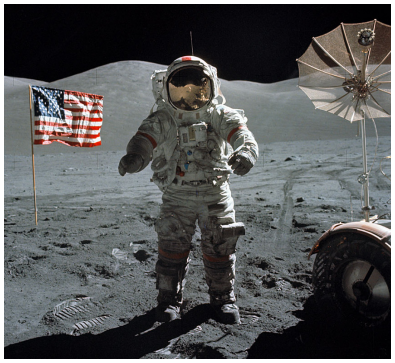

*Figure 1-2. Astronaut Gene Cernan as photographed by astronaut Jack Schmitt on the sixth and final Apollo exploration of the lunar surface in 1972. Source: NASA (Apollo 17)*

But that was 40 years ago. The last person to stand on the Moon returned to Earth 37 years ago. (See Figure 1-2.) Since the end of the Apollo Program, no American has traveled more than 386 miles from the surface of the Earth. Some 70 percent of Americans living today had not yet been born at the time of Apollo 11.

Today, the nation faces important decisions about the future of human spaceflight. Will we again leave the close proximity of low-Earth orbit and explore the solar system, charting a path for the eventual expansion of human civilization into space? If so, how will we ensure that our exploration delivers the greatest benefit to the nation? Can we explore with reasonable assurance of human safety? And can the nation marshal the resources to embark on the mission? Although there remain significant potential barriers to prolonged deep-space operations, which deserve greater attention than they are currently receiving (e.g., adaptation of humans to the micro-gravity and radiation environments of space away from the protective features of the Earth), the principal barrier to space operations continues to be its high cost compared with the resources that have been available.

Space exploration, initially a competitive pursuit, has become a global enterprise. Many other nations have aspirations in space, and the combined annual budgets of their space programs are comparable to NASA's. If the U.S. is willing to lead a global program of exploration, sharing both the burdens and benefits of space exploration in a meaningful way, significant benefits could follow. Actively engaging international partners in a manner adapted to today's multipolar world could strengthen geopolitical relationships, leverage global financial and technological resources, and enhance the exploration enterprise.

In addition, there is now a burgeoning commercial space industry. Given the appropriate incentives, this industry might help overcome a long-standing problem. The cost of admission to a variety of space activities strongly depends on the cost of reaching low-Earth orbit. These costs become even greater when, as is the circumstance today, large sums are paid to develop new launch systems but those systems are used only infrequently. It seems improbable that order-of-magnitude reductions in launch costs will be realized until launch rates increase substantially. But this is a "chicken-and-egg" problem. The early airlines faced a similar barrier, which was finally resolved when the federal government awarded a series of guaranteed contracts for carrying the mail. A corresponding action may be required if space is ever to become broadly accessible. If we craft a space architecture to provide opportunities to industry, creating an assured initial market, there is the potential—not without risk—that the eventual costs to the government could be reduced substantially.

Significantly, we are more experienced than we were in 1961, and we are able to build on that experience as we design an exploration program. If, after designing cleverly, building alliances with partners, and engaging commercial providers, the nation cannot afford to fund the effort to pursue the goals it would like to embrace, it should accept the disappointment of setting lesser goals. Whatever space program is ultimately selected, it must be matched with the resources needed for its execution. Here lies NASA's greatest peril of the past, present, and—absent decisive action—future. These challenging initiatives must be adequately funded, including reserves to account for the unforeseen and unforeseeable. (See Figure 1-3.)

| | Real Year Dollars (Billions) | 2009 Constant Dollars (Billions) Using GDP Deflator |
|---|---|---|
| **Mercury** (1959-1963) | 0.3 | 1.6 |
| **Gemini** (1962-1967) | 1.3 | 7.2 |
| **Apollo** (1961-1973) | 24.6 | 129.5 |
| **Shuttle** (1971-2009) | 112.8 | 172.5 |
| **ISS** (1994-2009) | 31.5 | 35.2 |
| **Constellation** (2006-2020) | 108.2 | 98.4 |

*Notes:*
*1. Mercury, Gemini, Apollo, Shuttle, and ISS costs are actual costs derived from historical budget documents.*
*2. Constellation costs are estimates that are supplied by the Constellation Program Office and based on an unconstrained budget that cumulates in a single Human Lunar return mission in 2020.*

*Figure 1-3. Human Spaceflight Programs Costs in Real Year and Constant Year 2009 Dollars. Source: NASA*

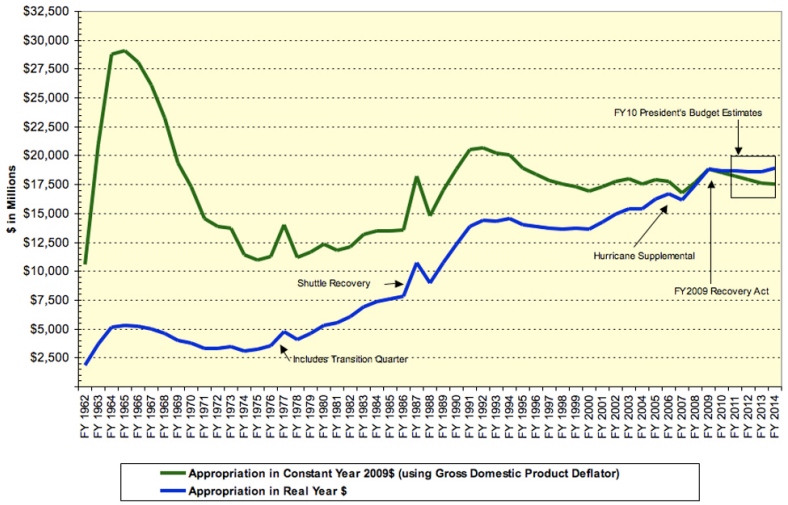


*Figure 1-4. NASA Appropriation History in Real Year and Constant Year 2009 Dollars. Source: OMB Historical Budget Tables*

Can we explore with reasonable assurance of human safety? Human space travel has many benefits, but it is an inherently dangerous endeavor. Past gains in launch systems reliability and safety have been realized at a painfully slow pace. Predictive models have generally proven unsatisfactory in accurately forecasting absolute reliability—many actual failures have been attributable to causes not included in most reliability models (e.g., process errors, design flaws, and, less frequently, operational errors). A great deal has been learned in building more reliable space systems, and this is not to suggest otherwise; rather, it is to confirm that this is an area deserving continuing attention. Human safety can never be absolutely assured, but throughout this report, safety is treated as the *sine qua non*. Concepts falling short in human safety have simply been eliminated from consideration. For example, no options proceeding *directly* to Mars have been offered as alternatives, because the Committee believes the state of technology, the understanding of risks, and the available operational experience are sufficiently immature—irrespective of the budgetary limitations—to commit to such an endeavor.

How will we explore to deliver the greatest benefit to the nation? Planning for a human spaceflight program should begin with a choice of goals—rather than a choice of destinations. Destinations should derive from goals, and alternative architectures may be weighed against those goals. There is now a strong consensus in the United States that the next step in human spaceflight should be to travel beyond low-Earth orbit. This promises to provide important benefits to society, including driving technological innovation; developing commercial industries and important national capabilities; and contributing to our expertise in further exploration. Human exploration *can* contribute appropriately to the expansion of scientific knowledge, especially field geology, and it is in the interest of both science and human spaceflight that a credible and well-rationalized strategy of coordination between the two endeavors be developed. Robotic spacecraft will play an important role as a precursor to human spaceflight activities. The Committee concluded that the ultimate goal of human exploration is to chart a path for human expansion into the solar system. This is an ambitious goal, but one worthy of U.S. leadership in concert with a broad range of international partners.

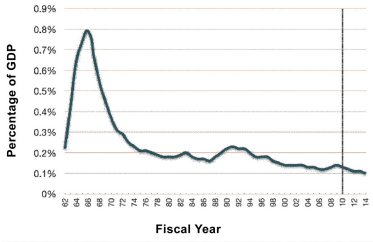


*Figure 1-5. As a percent of Gross Domestic Product the NASA budget has more or less continuously diminished since the peak of the Apollo program. Source: OMB Historical Budget Tables*





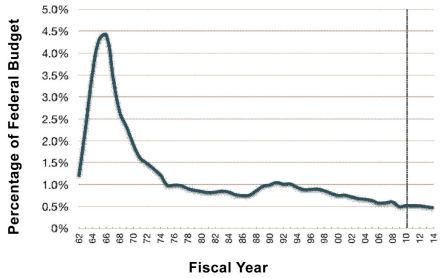


*Figure 1-6. The overall NASA budget as a fraction of the federal budget has declined from 4.5 percent at the peak of the Apollo program to approximately 0.5 percent today. Source: OMB Historical Budget Tables*

With regard to the human spaceflight program itself, the Committee has been deluged with strongly and genuinely held, frequently conflicting, beliefs as to the program's proper composition. For example, the following statements appeared in six different communications that happened to come across the Committee Chairman's desk within minutes of each other:

- *"As an American, having NASA field a retro-reenactment of the Apollo program to get back to the moon a half-century after we sent people there the first time is humiliating."*
- *"From a safety and continuity standpoint the next step in space must be a return to the moon."*
- *"I am an aerospace engineering master's candidate. [My classmates'] options are working for monolithic bureaucracies where their creativity will be crushed by program cancellations, cost overruns and risk aversion… It is no surprise that many of them choose to work in finance…"*
- *"We remember the past well and remind ourselves often of long gone civilizations whose innovations in science, technology and learning yielded knowledge that served as beacons of brilliance, but who lost the spark and faded."*
- *"…going back to the moon takes us into an intellectual and political cul de sac…"*
- *"The audacity to go to the moon was perhaps the 20th century's greatest illustration of America's optimism. Present generations of Americans need to capture some of that audacity."*

A primary issue in formulating a human spaceflight plan is its affordability. In the way of background, Figures 1-4, 1-5 and 1-6 present the overall NASA budget trend over time in absolute terms and in relationship to the GDP and the federal budget, respectively. The trend in funding the human spaceflight portion of NASA's portfolio is shown in Figure 1-7. Today, the human spaceflight program costs each citizen about seven cents a day.

So what should America's human spaceflight program look like? Before answering that question, we must face an underlying reality. We are where we are. The Committee thus identified five questions that could form the basis of a plan for U.S. human spaceflight:

- What should be the future of the Space Shuttle?
- What should be the future of the International Space Station?
- On what should the next heavy-lift launch vehicle be based?
- How should crew be carried to low-Earth orbit?
- What is the most practicable strategy for exploration beyond low-Earth orbit?


*Figure 1-7. Human spaceflight yearly annual budget in FY 2009 dollars (left scale) and as a percentage of total NASA budget (right scale.) Source: NASA*

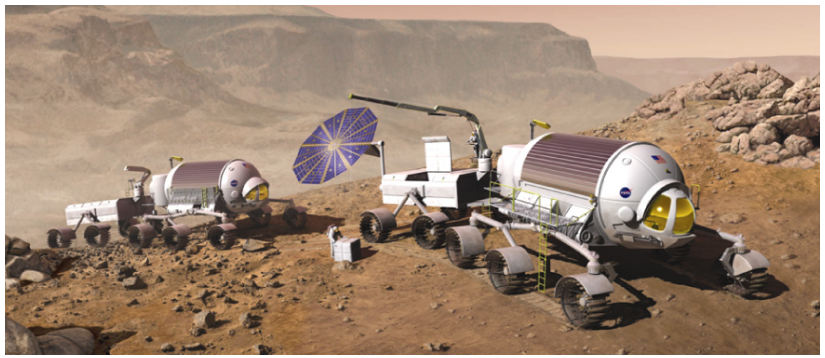

*Figure 1-8. Artist's concept of Mars mission activity. Source: NASA*

The Committee considers the framing of these questions, in a consistent way, to be at least as important as their combinations in the integrated options for a human spaceflight plan. The Committee assessed the programs within the current human spaceflight portfolio, considered capabilities and technologies that a future program might require, and examined the roles of commercial industry and our international partners in this enterprise.

A human landing and extended human presence on Mars stand prominently above all other opportunities for exploration. (See Figure 1-8.) Mars is unquestionably the most scientifically interesting destination in the inner solar system. It possesses resources which can be used for life support and propellants. If humans are ever to live for long periods with intention of extended settlement on another planetary surface, it is likely to be on Mars. But Mars is not an easy place to visit with existing technology and without a substantial investment in resources. The Committee concluded that Mars is the ultimate destination for human exploration of the inner solar system; but as already noted, it is not the best first destination.

The Committee thus addressed several possible strategies for exploration beyond low-Earth orbit. We could choose to explore the Moon first, with lunar surface exploration focused on developing the capability to explore Mars. Or we could choose to follow a flexible path to successively distant or challenging destinations, such as lunar orbit, Lagrange points, near-Earth objects, or the moons of Mars, which could lead to the possible exploration of the lunar surface and/or Martian surface.

As a result of its deliberations, the Committee developed five integrated options for the U.S. human spaceflight program that the Committee deems representative: one baseline case, founded upon the Constellation program, and four alternatives. Two of the options are constrained to the FY 2010 budget profile. The remaining three options, including the baseline, fit a less-constrained budget. It was possible to define some 3,000 potential options from the set of parameters considered—hence the options presented here should be thought of as representative families. Various program additions and deletions among these families are also plausible, with appropriate budget adjustments—including a proper accounting of the many interdependent facets of these integrated options. Several of these derivatives are discussed in this report.
The Committee considers it important for any exploration strategy to offer a spectrum of choices that provides periodic milestone accomplishments as well as a continuum of investment cost options. Unfortunately, for all options examined, the "entry cost" for human exploration is indeed significant—and for the more inspiring options there does not seem to be a "cost continuum." Put another way, there is a sizeable difference in the cost of programs between those operating in low-Earth orbit and those exploring beyond low-Earth orbit.

Clearly, a more penetrating analysis into any choice will be required before fully embarking upon it. However, the Committee believes it has fairly represented the most plausible courses. It bases this assessment in part on the extraordinary supporting effort provided by NASA personnel—an effort that was forthright, competent, and, in the NASA spirit, "can-do." The Committee also benefited significantly from prior independent reviews of NASA activities. In addition, the Committee contracted with the Aerospace Corporation to provide independent assessments. During the Committee's deliberations, it was informed by day-long public meetings in Houston, TX, Huntsville, AL, and Cocoa Beach, FL, as well as five days of meetings in Washington, DC. In addition, its subcommittees held





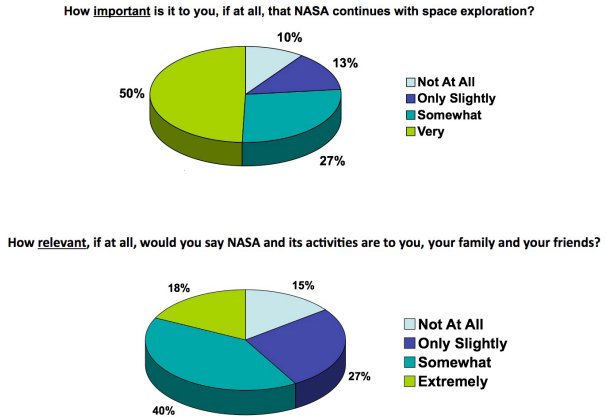


*Figure 1-9. Space exploration (human/robotic) continues to be valued by Americans – 77% think it is very or somewhat important, while 58% think it extremely or somewhat relevant. Source: NASA - 2009 Market Research Insights and Implications - August 6, 2009*

meetings in Denver, CO; Decatur, AL; Huntsville, AL; Michoud, LA; Hawthorne, CA; El Segundo, CA; and Dulles, VA. The group conducted numerous teleconference and videoconference preparatory sessions and communicated frequently by e-mail (over 1,700 e-mails in the Chairman's case).

Seeking to benefit from the views of the public, the Committee: established a website and Facebook site; used Twitter; conducted all decisional meetings in public session (meetings that were also carried on NASA TV); provided opportunity for public comment at five of the formal meetings; testified before committees of both the House and Senate; and held seven press conferences. Participation by the public was extensive—and the Committee made use of that input. It is heartening to note that the public still strongly supports the overall efforts of NASA. (See Figure 1-9.)

Finally, it is reasonable to ask whether a review over several months is sufficient to offer the options presented here. Certainly, the issues at hand demand a broad and detailed understanding of the human spaceflight program—ranging from an awareness of the impact of galactic cosmic rays on the human body to the fact that the hook-height at NASA's Michoud Assembly Facility will only allow the manufacture of a stage with a diameter of 33 feet.

Each of the Committee members had accrued extensive experience with spaceflight issues long before the beginning of this review. For example, the members cumulatively have amassed 245 days in orbit, 6 flights into space, 293 years working on space matters, 175 years in science, 144 years in engineering, 143 years in engineering management, 61 years in space operations, 77 years in government, 35 years in the military, and 160 years in the private sector. (The totals reflect the overlap of some of these categories.)

The Committee believes that the options presented here, if matched with appropriate funds, provide a reasonable foundation for selecting a human spaceflight program worthy of a great nation.