September 8, 2009

To: John P. Holdren, Director, Office of Science and Technology Policy

Charles F. Bolden, Jr., Administrator, National Aeronautics and Space Administration

Lori B. Garver, Deputy Administrator, National Aeronautics and Space Administration

Cc: Sally C. Ericsson, Program Associate Director, Office of Management and Budget

From: Review of U.S. Human Space Flight Plans Committee

Subject: Summary Report

Dear Dr. Holdren and Mr. Bolden,

On behalf of the Chairman of the Review of U.S. Human Space Flight Plans Committee, Norman Augustine, Edward Crawley, Sally Ride, and the other members of the Committee, please accept the attached Summary Report.

This Summary Report provides an overview of the key findings, options, and issues identified by the Committee during its review of the U.S. human space flight plans and program.

The committee is currently engaged in preparing the Final Report for delivery to you. The Final Report will provide more detail and depth to the attached Summary Report and will include the supporting analyses from the Committee's review.

SUMMARY REPORT
of the
Review of U.S. Human Space Flight Plans Committee

The U.S. human spaceflight program appears to be on an unsustainable trajectory. It is perpetuating the perilous practice of pursuing goals that do not match allocated resources. Space operations are among the most complex and unforgiving pursuits 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 nation is facing important decisions on the future of human spaceflight. Will we leave the close proximity of low-Earth orbit, where astronauts have circled since 1972, 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 assurances of human safety? And, can the nation marshal the resources to embark on the mission?

Whatever space program is ultimately selected, it must be matched with the resources needed for its execution. How can we marshal the necessary resources? There are actually more options available today than in 1961 when President Kennedy challenged NASA and the nation to "land a man on the Moon by the end of the decade."

First, space exploration has become a global enterprise. Many nations have aspirations in space, and the combined annual budgets of their space programs are comparable to NASA's. If the United States is willing to lead a global program of exploration, sharing both the burden and benefit of space exploration in a meaningful way, significant benefits could follow. Actively engaging international partners in a manner adapted to today's multi-polar world could strengthen geopolitical relationships, leverage global resources, and enhance the exploration enterprise.

Second, there is now a burgeoning commercial space industry. If we craft the space architecture to provide opportunities to this industry, there is the potential—not without risk—that the costs to the government would be reduced. Finally, we are also more experienced than in 1961, and 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.

Can we explore with reasonable assurances of human safety? Human space travel has many benefits, but it is an inherently dangerous endeavor. Human safety can never be absolutely assured, but throughout this report, it is treated as a *sine qua non*. It is not discussed in extensive detail because any concepts falling short in human safety have simply been eliminated from consideration.

How will we explore to deliver the greatest benefit to the nation? Planning for a human spaceflight program should begin with a choice about its goals—rather than a choice of possible 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 is to travel beyond low-Earth orbit. This should carry 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, particularly in areas such as field geology, and it is in the interest of both science and human spaceflight that a credible and well-rationalized strategy of coordination between them be developed. Crucially, human spaceflight objectives should broadly align with key national objectives.

These more tangible benefits exist within a larger context. Exploration provides an opportunity to demonstrate space leadership while deeply engaging international partners; to inspire the next generation of scientists and engineers; and to shape human perceptions of our place in the universe. 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.

The Committee's task was to review the U.S. plans for human spaceflight. In doing so, it assessed the programs within the current human spaceflight portfolio; considered capabilities and technologies a future program might require; and considered the roles of commercial industry and our international partners in this enterprise. From these deliberations, the Committee developed five integrated alternatives for the U.S. human spaceflight program. The considerations and the five alternatives are summarized in the pages that follow.

Key Questions to Guide the Plan for Human Spaceflight

The Committee identified the following questions that, if answered, would form the basis of a plan for U.S. human spaceflight:

1. What should be the future of the Space Shuttle?
2. What should be the future of the International Space Station (ISS)?
3. On what should the next heavy-lift launch vehicle be based?
4. How should crews be carried to low-Earth orbit?
5. What is the most practicable strategy for exploration *beyond* low-Earth orbit?

The Committee considers the framing and answering of these questions individually, and in a consistent way, to be at least as important as their combinations in the integrated options for a human spaceflight program.

1.0 CURRENT PROGRAMS

Before addressing options for the future human exploration program, it is appropriate to discuss the current programs: the Space Shuttle, ISS and Constellation, as well as the looming problem of "the Gap."

1.1. Space Shuttle

What should be the future of the Space Shuttle? The present plan is to retire it at the end of FY 2010, with its final flight scheduled for the last month of that fiscal year. Although the current Administration has relaxed the requirement to complete the last mission before the end of FY 2010, there are no funds in the FY 2011 budget for continuing Shuttle operations.

In considering the future of the Shuttle, the Committee assessed the realism of the current schedule; examined issues related to Shuttle workforce, reliability and cost; and weighed the risks and possible benefits of a Shuttle extension. The Committee noted that the projected flight rate is nearly twice that of the actual flight rate since return to flight after the *Columbia* accident. Recognizing that undue schedule and budget pressure can subtly impose a negative influence on safety, the Committee finds that a more realistic schedule is prudent. With the remaining flights likely to stretch into the second quarter of 2011, the Committee considers it important to budget for Shuttle operations through that time.

Although a thorough analysis of Shuttle safety was not part of its charter, the Committee did examine the Shuttle's safety record and reliability. New human-rated launch vehicles will likely be more reliable once they reach maturity, but in the meantime, the Shuttle is in the enviable position of being through its infant mortality phase. Its flight experience and demonstrated reliability should not be discounted.

Once the Shuttle is retired, there will be a gap in America's capability to launch humans into space. That gap will extend until the next U.S. human-rated launch system becomes available. The Committee estimates that, under the current plan, this gap will be at least seven years long. There has not been this long a gap in U.S. human launch capability since the U.S. human space program began.

Most of the integrated options presented below would retire the Shuttle after a prudent fly-out of the current manifest, indicating that the Committee found the interim reliance on international crew services acceptable. However, one option does provide for an extension of Shuttle at a minimum safe flight rate to preserve U.S. capability to launch astronauts into space. If that option is selected, there should be a thorough review of Shuttle recertification conducted to date and overall Shuttle reliability to ensure that the risk associated with that extension would be acceptable. This review should be performed by an independent committee, with the purpose to ensure that NASA has met the intent behind the relevant recommendation of the Columbia Accident Investigation Board.[1]

1.2 International Space Station

In considering the future of the International Space Station (ISS), the Committee asked two basic questions: What is the outlook between now and 2015? Should ISS be extended beyond 2015?

[1] "Prior to operating the Shuttle beyond 2010, develop and conduct a vehicle recertification at the material, component, subsystem, and system levels. Recertification requirements should be included in the Service Life Extension Program." [Columbia Accident Investigation Board, R9.2-1]

The Committee is concerned that the ISS, and particularly its utilization, may be vulnerable after Shuttle retirement. ISS was designed, assembled and operated with the capabilities of the Space Shuttle in mind. The present approach to its utilization is based on Shuttle-era experience. After Shuttle retirement, ISS will rely on a combination of new, and as yet unproven, international and commercial vehicles for cargo transport. Because the planned commercial resupply capability will be crucial to both ISS operations and utilization, it may be prudent to strengthen the incentives to the commercial providers to meet the schedule milestones.

Now that the ISS is nearly completed and is staffed by a full crew of six, its future success will depend on how well it is used. Up to now, the focus has been on assembling ISS, and this has come at the expense of using the Station. Utilization should have first priority in the years ahead.

The Committee finds that the return on investment of ISS to both the United States and the international partners would be significantly enhanced by an extension of ISS life to 2020. It seems unwise to de-orbit the Station after 25 years of assembly and only five years of operational life. *Not* to extend its operation would significantly impair U.S. ability to develop and lead future international spaceflight partnerships. Further, the ISS should be funded to enable it to achieve its full potential: as the nation's newest national laboratory, as an enhanced test bed for technologies and operational techniques that support exploration, and as a framework that can support expanded international collaboration.

The strong and tested working relationship among international partners is perhaps the most important outcome of the ISS program. The partnership expresses a "first among equals" U.S. leadership style adapted to today's multi-polar world. That leadership could extend to exploration, as the ISS partners could engage at an early stage if aspects of exploration beyond low-Earth orbit were included in the goals of the partnership agreement.

1.3 The Constellation Program

The Constellation Program includes: the Ares I launch vehicle, capable of launching astronauts to low-Earth orbit; the Ares V heavy-lift launch vehicle, to send astronauts and equipment to the Moon; the Orion capsule, intended to carry astronauts to low-Earth orbit and beyond; and the Altair lunar lander and lunar surface systems astronauts will need to explore the lunar surface. As the Committee assessed the current status and possible future of the Constellation Program, it reviewed the technical, budgetary and schedule challenges that the program faces today.

Given the funding originally expected, the Constellation Program was a reasonable architecture for human exploration. However, even when it was announced, its budget depended on funds becoming available from the retirement of the Space Shuttle in 2010 and the decommissioning of ISS in early 2016. Since then, as a result of technical and budgetary issues, the development schedules of Ares I and Orion have slipped, and work on Ares V and Altair has been delayed.

Most major vehicle-development programs face technical challenges as a normal part of the process, and Constellation is no exception. While significant, these are engineering problems, and the Committee expects that they can be solved. But these solutions may add to the program's cost and/or delay its schedule.

The original 2005 schedule showed Ares I and Orion available to support ISS in 2012, only two years after scheduled Shuttle retirement. The current schedule now shows that date as 2015. An independent assessment of the technical, budgetary and schedule risk to the Constellation Program performed for the Committee indicates that an additional delay of at least two years is likely.[2] This means that Ares I and Orion will not reach ISS before the Station's currently planned termination, and the length of the gap in U.S. ability to launch astronauts into space will be no less than seven years.

The Committee also examined the design and development of Orion. Many concepts are possible for crew-exploration vehicles, and NASA clearly needs a new spacecraft for travel beyond low-Earth orbit. The Committee found no compelling evidence that the current design will not be acceptable for its wide variety of tasks in the exploration program. However, the Committee is concerned about Orion's recurring costs. The capsule is considerably larger and more massive than previous capsules (e.g., the Apollo capsule), and there is some indication that a smaller and lighter four-person Orion could reduce operational costs. However, a redesign of this magnitude would likely result in over a year of additional development time and a significant increase in cost, so such a redesign should be considered carefully before being implemented.

2.0 CABABILITY FOR LAUNCH TO LOW-EARTH ORBIT AND EXPLORATION BEYOND

2.1 Heavy-Lift Launch to Low-Earth Orbit and Beyond:

No one knows the mass or dimensions of the largest piece that will be required for future exploration missions, but it will likely be significantly larger than 25 metric tons (mt) in launch mass to low-Earth orbit, the capability of current launchers. As the size of the launcher increases, fewer launches and less operational complexity to assemble and/or refuel them results, and the net availability of launch capability increases. Combined with considerations of launch availability and on-orbit operations, the Committee finds that exploration will benefit from the availability of a heavy-lift vehicle. In addition, heavy lift would enable the launching of large scientific observatories and more capable deep-space missions. It may also provide benefit in national security applications. The question is: On what system should the next heavy-lift launch vehicle be based?

<table>
<tr><th colspan="3">Family</th><th>Launch Mass to LEO</th></tr>
<tr><td rowspan="3">NASA Heritage</td><td rowspan="2">Ares Family</td><td>Ares V + Ares I</td><td>160 mt + 25 mt</td></tr>
<tr><td>Ares V Lite</td><td>140 mt</td></tr>
<tr><td colspan="2">Shuttle Derived Family</td><td>100 -110 mt</td></tr>
<tr><td colspan="3">EELV Heritage Family</td><td>75 mt</td></tr>
</table>

Table 2-1. Characteristics of heavy-lift launch vehicles, indicating the EELV and NASA heritage families.

[2] The independent assessment was conducted for the Committee by the Aerospace Corporation.

Potential approaches to developing heavy-lift vehicles (Table 2-1) are based on NASA heritage (Shuttle and Apollo) and EELV (evolved expendable launch vehicle) heritage. Each has its distinct advantages and disadvantages.

In the Ares-V-plus-Ares-I system planned by the Constellation program, the Ares I launches the Orion and docks in low-Earth orbit with the Altair lander launched on the Ares V. It has the advantage of projected very high ascent crew safety, but it delays the development of the Ares V heavy lift vehicle until after the independently operated Ares I is developed.

In a different, related architecture, the Orion and Altair are launched on two separate "Lite" versions of the Ares V, providing for more robust mass margins. Building a single NASA vehicle could reduce carrying and operations costs, and accelerate heavy-lift development. Of these two Ares system alternatives, the Committee finds the Ares V Lite in the dual mode the preferred reference option.

The more directly Shuttle-derived family consists of in-line and side-mount vehicles substantially derived from the Shuttle, providing more continuity in workforce. The development cost of the more Shuttle-derived system would be lower, but it would be less capable than the Ares V family and have higher recurring costs. The lower launch capability could eventually be offset by developing on-orbit refueling.

The EELV-heritage systems have the least lift capability, so that to provide equal performance, almost twice as many launches would be required, when compared to the Ares family. If on-orbit refueling were developed and used, the number of launches could be reduced, but operational complexity would be added. However, the EELV approach would also represent a new way of doing business for NASA, which would have the benefit of potentially lowering development and operational costs. This would come at the cost of ending a substantial portion of the internal NASA capability to develop and operate launchers. It would also require that NASA and the Department of Defense jointly develop the new system.

All of the options would benefit from the development of in-space refueling, and the smaller rockets would benefit most of all. The potential government-guaranteed market for fuel in low-Earth orbit would create a stimulus to the commercial launch industry. In the design of the new launcher, in-space stages and in-space refueling, the Committee cautions against the tradition of designing for ultimate performance, at the cost of reliability, operational efficiency and life-cycle cost.

2.2 Crew Access to Low-Earth Orbit

How should U.S. astronauts be transported to low-Earth orbit? There are two basic approaches: a government-operated system and a commercial crew-delivery service. The current Constellation Program plan is to use the government-operated Ares I launch vehicle and the Orion crew capsule. However, the Committee found that, because of technical and budget issues, the Ares I schedule no longer supports the ISS.

Ares I was designed to a high standard in order to provide astronauts with access to low-Earth orbit at lower risk and a considerably higher level of reliability than is available today. To achieve this, it uses a high-reliability rocket and a crew capsule with a launch-escape system. But other potential combinations of high-reliability rockets and capsules with escape systems could also provide that reliability. The Committee was unconvinced that enough is known about any of the

potential high-reliability launcher-plus-capsule systems to distinguish their levels of safety in a meaningful way.

The United States needs a way to launch astronauts to low-Earth orbit, but it does not necessarily have to be provided by the government. As we move from the complex, reusable Shuttle back to a simpler, smaller capsule, it is an appropriate time to consider turning this transport service over to the commercial sector. This approach is not without technical and programmatic risks, but it creates the possibility of lower operating costs for the system and potentially accelerates the availability of U.S. access to low-Earth orbit by about a year, to 2016. The Committee suggests establishing a new competition for this service, in which both large and small companies could participate.

2.3 Lowering the cost of space exploration

The cost of exploration is dominated by the costs of launch to low-Earth orbit and of the in-space systems. It seems improbable that significant reductions in launch costs will be realized in the short term until launch rates increase substantially—perhaps through expanded commercial activity in space. How can the nation stimulate such activity? In the 1920s, the federal government awarded a series of guaranteed contracts for carrying airmail, stimulating the growth of the airline industry. The Committee concludes that an architecture for exploration employing a similar policy of guaranteed contracts has the potential to stimulate a vigorous and competitive commercial space industry. Such commercial ventures could include supply of cargo to the ISS (already underway), transport of crew to orbit and transport of fuel to orbit. Establishing these commercial opportunities could increase launch volume and potentially lower costs to NASA and all other launch-services customers.

This would have the additional benefit of focusing NASA on a more challenging role, permitting it to concentrate its efforts where its inherent capability resides: for example, developing cutting-edge technologies and concepts, and defining programs and overseeing the development and operation of exploration systems, particularly those beyond low-Earth orbit.

The Committee strongly believes it is time for NASA to reassume its crucial role of developing new technologies for space. Today, the alternatives available for exploration systems are severely limited because of the lack of a strategic investment in technology development in past decades. NASA now has an opportunity to develop a technology roadmap that is aligned with an exploration mission that will last for decades. If appropriately funded, a technology development program would re-engage the minds at American universities, in industry and within NASA. The investments should be designed to increase the capabilities and reduce the costs of future exploration. This will benefit human and robotic exploration, the commercial space community, and other U.S. government users.

3.0 FUTURE DESTINATIONS FOR EXPLORATION

What is the strategy for exploration beyond low-Earth orbit? Humans could embark on the following paths to explore the inner solar system:

- Mars first, with a Mars landing, perhaps after a brief test of equipment and procedures on the Moon.

- Moon first, with lunar surface exploration focused on developing the capability to explore Mars.
- Flexible path to inner solar system locations, such as lunar orbit, Lagrange points, near-Earth objects and the moons of Mars, followed by exploration of the lunar surface and/or Martian surface.

A human landing followed by an extended human presence on Mars stands prominently above all other opportunities for exploration. Mars is unquestionably the most scientifically interesting destination in the inner solar system, with a history much like Earth's. It possesses resources, which can be used for life support and propellants. If humans are ever to live for long periods 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 of resources. The Committee finds that Mars is the ultimate destination for human exploration; but it is not the best first destination.

What about the Moon first, then Mars? By first exploring the Moon, we could develop the operational skills and technology for landing on, launching from and working on a planetary surface. In the process, we could acquire an understanding of human adaptation to another world that would one day allow us to go to Mars.

There are two main strategies for exploring the Moon. Both begin with a few short sorties to various sites to scout the region and validate the lunar landing and ascent systems. In one strategy, the next step would be to build a base. Over many missions, a small colony of habitats would be assembled, and explorers would begin to live there for many months, conducting scientific studies and prospecting for resources that could be used as fuel. In the other strategy, sorties would continue to different sites, spending weeks and then months at each one. More equipment would have to be brought on each trip, but more diverse sites would be explored and in greater detail.

There is a third possible path for human exploration beyond low-Earth orbit, which the Committee calls the Flexible Path. On this path, humans would visit sites never visited before and extend our knowledge of how to operate in space—while traveling greater and greater distances from Earth. Successive missions would visit: lunar orbit; the Lagrange points (special points in space that are important sites for scientific observations and the future space transportation infrastructure); near-Earth objects (asteroids that cross the Earth's path); and orbit around Mars. Most interestingly, humans could rendezvous with a moon of Mars, then coordinate with or control robots on the Martian surface.

The Flexible Path represents a different type of exploration strategy. We would learn how to live and work in space, to visit small bodies, and to work with robotic probes on the planetary surface. It would provide the public and other stakeholders with a series of interesting "firsts" to keep them engaged and supportive. Most important, because the path is flexible, it would allow many different options as exploration progresses, including a return to the Moon's surface, or a continuation to the surface of Mars.

The Committee finds that both Moon First and Flexible Path are viable exploration strategies. It also finds that they are not necessarily mutually exclusive; before traveling to Mars, we might be well served to both extend our presence in free space and gain experience working on the lunar surface.

4.0 INTEGRATED PROGRAM OPTIONS

The Committee has identified five principal alternatives for the human spaceflight program. They include one baseline case, which the Committee believes to be an executable version of the current program of record, funded to achieve its stated exploration goals, as well as four alternatives. These options are summarized in Table 4-1.

	Budget	Shuttle Life	ISS Life	Heavy Launch	Crew to LEO
Constrained Options					
Option 1: Program of Record (constained)	FY10 Budget	2011	2015	Ares V	Ares I + Orion
Option 2: ISS + Lunar (constrained)	FY10 Budget	2011	2020	Ares V Lite	Commercial
Moon First Options					
Option 3: Baseline - Program of Record	Less constrained	2011	2015	Ares V	Ares I + Orion
Option 4A: Moon First - Ares Lite	Less constrained	2011	2020	Ares V Lite	Commercial
Option 4B: Moon First - Extend Shuttle	Less constrained	2015	2020	Directly Shuttle Derived + refueling	Commercial
Flexible Path Options					
Option 5A: Flexible Path - Ares Lite	Less constrained	2011	2020	Ares V Lite	Commercial
Option 5B:Flexible Path - EELV Heritage	Less constrained	2011	2020	75mt EELV + refueling	Commercial
Option 5C: Flexible Path - Shuttle Derived	Less constrained	2011	2020	Directly Shuttle Derived + refueling	Commercial

Note: Program-of-Record-derived options (Options 1 and 3) do not contain a technology program; all others do.

Table 4-1. A summary of the integrated program options.

The committee was asked to provide two options that fit within the FY 2010 budget profile. This funding is essentially flat or decreasing through 2014, then increases at 1.4 percent per year thereafter, which is less than the 2.4 percent per year used to estimate cost inflation. The first two options are constrained to that budget.

Option 1. Program of Record as assessed by the Committee, constrained to the FY 2010 budget. This option is the Program of Record, with only two changes the Committee deems necessary: providing funds for the Shuttle into FY 2011 and including sufficient funds to de-orbit the ISS in 2016. When constrained to this budget profile, Ares I and Orion are not available until after the ISS has been de-orbited. The heavy-lift vehicle, Ares V, is not available until the late 2020s, and worse, there are insufficient funds to develop the lunar lander and lunar surface systems until well into the 2030s, if ever.

Option 2. ISS and Lunar Exploration, constrained to FY 2010 budget. This option extends the ISS to 2020, and it begins a program of lunar exploration using Ares V (Lite). The option assumes Shuttle fly-out in FY 2011, and it includes a technology development program, a program to develop commercial crew services to low-Earth orbit, and funds for enhanced utilization of ISS. This option does not deliver heavy-lift capability until the late 2020s and does not have funds to develop the systems needed to land on or explore the Moon.

The remaining three alternatives are fit to a different budget profile—one that the Committee judged more appropriate for an exploration program designed to carry humans beyond low-Earth orbit. This budget increases to $3 billion above the FY 2010 guidance by FY 2014, then grows with inflation at a more reasonable 2.4 percent per year.

Option 3. Baseline Case —Implementable Program of Record. This is an executable version of the program of record. It consists of the content and sequence of that program – de-orbiting the ISS in 2016, developing Orion, Ares I and Ares V, and beginning exploration of the Moon. The Committee made only two additions it felt essential: budgeting for the fly-out of the Shuttle in 2011 and including additional funds for ISS de-orbit. The Committee's assessment is that, under this funding profile, the option delivers Ares1/Orion in FY 2017, with human lunar return in the mid-2020s.

Option 4. Moon First. This option preserves the Moon as the first destination for human exploration beyond low-Earth orbit. It also extends the ISS to 2020, funds technology advancement, and uses commercial vehicles to carry crew to low-Earth orbit. There are two significantly different variants to this option.

Variant 4A is the Ares Lite variant. This retires the Shuttle in FY 2011 and develops the Ares V (Lite) heavy-lift launcher for lunar exploration. *Variant 4B* is the Shuttle extension variant. This variant includes the only foreseeable way to eliminate the gap in U.S. human-launch capability: it extends the Shuttle to 2015 at a minimum safe-flight rate. It also takes advantage of synergy with the Shuttle by developing a heavy-lift vehicle that is more directly Shuttle-derived. Both variants of Option 4 permit human lunar return by the mid-2020s.

Option 5. Flexible Path. This option follows the Flexible Path as an exploration strategy. It operates the Shuttle into FY 2011, extends the ISS until 2020, funds technology development and develops commercial crew services to low-Earth orbit. There are three variants within this option; they differ only in the heavy-lift vehicle.

Variant 5A is the Ares Lite variant. It develops the Ares Lite, the most capable of the heavy-lift vehicles in this option. *Variant 5B* employs an EELV-heritage commercial heavy-lift launcher and assumes a different (and significantly reduced) role for NASA. It has an advantage of potentially lower operational costs, but requires significant restructuring of NASA. *Variant 5C* uses a directly Shuttle-derived, heavy-lift vehicle, taking maximum advantage of existing infrastructure, facilities and production capabilities.

All variants of Option 5 begin exploration along the flexible path in the early 2020s, with lunar fly-bys, visits to Lagrange points and near-Earth objects and Mars fly-bys occurring at a rate of about one major event per year, and possible rendezvous with Mars's moons or human lunar return by the mid to late 2020s.

The Committee has found two executable options that comply with the FY 2010 budget. However, neither allows for a viable exploration program. In fact, the Committee finds that no plan compatible with the FY 2010 budget profile permits human exploration to continue in any meaningful way.

The Committee further finds that it is possible to conduct a viable exploration program with a budget rising to about $3 billion annually above the FY 2010 budget profile. At this budget level, both the Moon First strategy and the Flexible Path strategies begin human exploration on a

reasonable, though hardly aggressive, timetable. The Committee believes an exploration program that will be a source of pride for the nation requires resources at such a level.

5.0 ORGANIZATIONAL AND PROGRAMMATIC ISSUES

How might NASA organize to explore? The NASA Administrator needs to be given the authority to manage NASA's resources, including its workforce and facilities. Even the best-managed human spaceflight programs will encounter developmental problems. Such activities must be adequately funded, including reserves to account for the unforeseen and unforeseeable. Good management is especially difficult when funds cannot be moved from one human spaceflight budget line to another—and where new funds can ordinarily be obtained only after a two-year delay (if at all). NASA should be given the maximum flexibility possible under the law to establish and manage its systems.

Finally, significant space achievements require continuity of support over many years. One way to ensure that no successes are achieved is to continually pull up the flowers to see if the roots are healthy. (This Committee might be accused of being part of this pattern!) NASA and its human spaceflight program are in need of stability in both resources and direction.

6.0 SUMMARY OF KEY FINDINGS

The Committee summarizes its key findings below. Additional findings are included in the body of the report.

The right mission and the right size: NASA's budget should match its mission and goals. Further, NASA should be given the ability to shape its organization and infrastructure accordingly, while maintaining facilities deemed to be of national importance.

International partnerships: The U.S. can lead a bold new international effort in the human exploration of space. If international partners are actively engaged, including on the "critical path" to success, there could be substantial benefits to foreign relations, and more resources overall could become available.

Short-term Space Shuttle planning: The current Shuttle manifest should be flown in a safe and prudent manner. The current manifest will likely extend to the second quarter of FY 2011. It is important to budget for this likelihood.

The human-spaceflight gap: Under current conditions, the gap in U.S. ability to launch astronauts into space will stretch to at least seven years. The Committee did not identify any credible approach employing new capabilities that could shorten the gap to less than six years. The only way to significantly close the gap is to extend the life of the Shuttle Program.

Extending the International Space Station: The return on investment to both the United States and our international partners would be significantly enhanced by an extension of ISS life. *Not* to extend its operation would significantly impair U.S. ability to develop and lead future international spaceflight partnerships.

Heavy-lift: A heavy-lift launch capability to low-Earth orbit, combined with the ability to inject heavy payloads away from the Earth, is beneficial to exploration, and it also will be useful to the national security space and scientific communities. The Committee reviewed: the Ares family of launchers; more directly Shuttle-derived vehicles; and launchers derived from the EELV family. Each approach has advantages and disadvantages, trading capability, lifecycle costs, operational complexity and the "way of doing business" within the program and NASA.

Commercial crew launch to low-Earth orbit: Commercial services to deliver crew to low-Earth orbit are within reach. While this presents some risk, it could provide an earlier capability at lower initial and lifecycle costs than government could achieve. A new competition with adequate incentives should be open to all U.S. aerospace companies. This would allow NASA to focus on more challenging roles, including human exploration *beyond* low-Earth orbit, based on the continued development of the current or modified Orion spacecraft.

Technology development for exploration and commercial space: Investment in a well-designed and adequately funded space technology program is critical to enable progress in exploration. Exploration strategies can proceed more readily and economically if the requisite technology has been developed in advance. This investment will also benefit robotic exploration, the U.S. commercial space industry and other U.S. government users.

Pathways to Mars: Mars is the ultimate destination for human exploration; but it is not the best first destination. Both visiting the Moon First and following the Flexible Path are viable exploration strategies. The two are not necessarily mutually exclusive; before traveling to Mars, we might be well served to both extend our presence in free space and gain experience working on the lunar surface.

Options for the Human Spaceflight Program: The Committee developed five alternatives for the Human Spaceflight Program. It found:

- Human exploration beyond low-Earth orbit is not viable under the FY 2010 budget guideline.
- Meaningful human exploration is possible under a less constrained budget, ramping to approximately $3 billion per year above the FY 2010 guidance in total resources.
- Funding at the increased level would allow either an exploration program to explore Moon First or one that follows a Flexible Path of exploration. Either could produce results in a reasonable timeframe.