A New Paradigm for Space Exploration
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Thank you for inviting me to discuss the President's vision for space exploration. This Committee has long supported strong Federal science and technology. We believe the Nation's space enterprise will be strengthened by a new focus that only a long-term vision can provide. With a sustainable, long-term vision, NASA will continue a record of discovery that in recent decades has literally changed the way we view the universe. I look forward to your continued support and to working with this Committee to realize this vision for space exploration.

Vision Background and Rationale

Neil Armstrong's first footsteps on the Moon in 1969 inspired wonder and excitement throughout the world. In that moment it seemed the unimaginable had become reality, and a course established for an enterprise in space in which anything was possible. Those first footsteps continue to inspire new generations of young scientists and engineers.

Today we know much more about the difficulties of space exploration by humans or machines, and our thinking about space has evolved with our growing awareness of its costs and hazards. Against the background of that experience, the President has provided a general plan for space exploration that is at once visionary and pragmatic. Described by the President as "*a journey, not a race*," this plan differs profoundly from the Apollo paradigm of a single massive project requiring a large budget spike and an aggressive schedule. In this new vision, milestones are established to guide planning on a series of discrete and mutually reinforcing projects, whose aim at each step is to reduce the cost and risk of all subsequent missions.

Costs and risks are inherent in space exploration. The costs begin with the need to use rockets with their inherent massive fuel requirements to lift even small payloads away from Earth. The risks come from the hostile space environment, weightlessness, and the need to execute complex operations at immense distances from Earth, with mission durations measured not in weeks or months, but years.

The President's new paradigm takes these facts seriously, balances robotic and human roles in dealing with them, and mandates a step-by-step approach to address the risks and costs within a steady and realistic flow of resources. With respect to human exploration, it implies a fundamental change in ground rules. The idea, in the President's words, is to "*explore space and extend a human presence across our solar system.... [making] steady progress – one mission, one voyage, one landing at a time.*" The emphasis is on sustained exploration and discovery through all appropriate means, at a pace we can afford in terms of risk as well as cost.

The new paradigm also acknowledges the stark fact that the Moon is the nearest platform beyond low earth orbit that can sustain the entire range of activities one would like to conduct in space. It is not just a more remote version of the International Space Station. It has the potential of providing mass for a variety of uses for further exploration missions, and consequently significantly reducing future costs. Some lunar resources may be valuable for Earth satellite applications. The long-term value of the Moon is not primarily in its direct value to science, but in its value to all future deep space operations.

Deliberative Process

My office has been involved from the outset in developing this vision. OSTP, NASA, and most segments of the space community recognized the need for a civilian space vision. This need took on a new sense of urgency on February 1, 2003, when the Shuttle *Columbia* was lost. Starting in spring 2003 a group from the White House, NASA, and other agencies began sorting out the relevant issues. Upon the release of the Columbia Accident Investigation Board report, which echoed the need for such a vision, the White House established a formal policy process co-chaired by the National Security Council and the Domestic Policy Council. I was directly involved in providing technical support to the process and I was involved in each of the senior meetings, as was Administrator O'Keefe. My staff was engaged in the process on a daily basis. In this context, a consensus vision and implementation strategy emerged.

This process occurred in an environment rich with information about space exploration. Numerous reports and analyses, produced over decades, have considered the future of civil space exploration in great detail. Tradeoffs between human and robotic capabilities have been debated, passionate discourses have been written about the ultimate destination – whether it should be the Moon, Mars, or a Lagrangian point, and the ultimate wisdom of committing the resources to set our sights beyond planet Earth. These analyses and inputs were used to inform the discussion and to frame the vision articulated by the President.

Exploration Opportunities

The President's new paradigm will open up new opportunities to explore and understand the cosmos that are not technically possible today. During the first 40 years of NASA's exploration, of the solar system, the available technology and resources have allowed for flyby missions of numerous moons, asteroids, comets, and every planet except Pluto. In a few cases, orbital missions were executed (the Moon, Venus, Mars, Jupiter, and the asteroid Eros) and in even fewer cases, landings were made (the Moon, Venus, and Mars).

During the same period, space observatories have become increasingly more sophisticated, opening up windows of observation that are impossible from the ground. Data from these facilities have transformed our understanding of the formation and evolution of the Universe.

Further major advances in understanding the Solar System and the universe will likely require even more complex operations in space or on the surface of solar system objects. These would involve high power instrumentation, large area and long-duration investigation of multiple planetary bodies, and the possible assembly of sophisticated observatories.

Such complex missions are not possible today for several reasons including: the small payload mass we can affordably send into deep space; limitations in power due to decreasing solar flux at high latitudes on near planets or deeper into space; slow communications data rates to Earth; and the challenge of programming autonomous missions and controlling operations from Earth given the large time delays imposed by the finite speed of light.

These “infrastructure” issues are inter-related and their resolution will provide the backbone for a robust exploration agenda – an agenda that allows for close-in examination, the ability to touch the item under scrutiny, and the evaluation of large area and long-term trends. The President's vision also establishes a balance between robots and humans, using the strengths of each to optimize the complex missions.

The President’s vision and its budget call for the deliberate development of the capabilities needed to open up the Universe to increased scrutiny. It will create new transportation options for both robots and humans, harness the natural resources found in space to foster sustainability, develop robust high power systems, improve communications, and build vastly more capable robots and improved robotic-human interfaces.

Near-Term Science and Technology Enablers
There are several important enabling initiatives outlined in the vision:

<u>International Space Station (ISS):</u> The ISS provides an important laboratory for understanding the effects of the hostile space environment on human health and well being. The emphasis of the U.S. research on the Station will be refocused to support space exploration goals, including counteracting the impact of the space environment on human health and advanced life support systems. The U.S. research on the ISS will leverage terrestrial laboratory work to develop a more complete understanding of the effects of the space environment on human physiology and to develop countermeasures.

<u>Moon:</u> We will return to the Moon as a first step to opening the Solar System to further human exploration, including Mars missions. The first missions will be robotic and will provide a more detailed assessment of the material composition and variability across the lunar surface and will help to resolve uncertainty in our understanding of the formation and early geological history and subsequent evolution of the Earth and the other inner planets. Furthermore, the lunar missions will demonstrate our ability to live and work on another world. Apollo demonstrated that we could transport humans to the Moon, land, and return safely. The six Apollo flights that landed on the Moon spent a sum total of less than 300 hours on the lunar surface (less than 13 days). While we have demonstrated in the past that we can land on the Moon and return safely to Earth, we must now demonstrate that we can build and operate an infrastructure capable of supporting life for many months in an alien, inhospitable environment far from home. Furthermore, as previously described, the Moon is potentially a rich source of materials. Previous space commissions and studies have emphasized that extracted resources from the lunar surface can greatly enhance our ability to explore the solar system by refueling rockets; providing metals, ceramics, and other materials; and sustaining more cost-effective access to Mars and other worlds by launching materials from the Moon rather than from the Earth’s surface.

<u>Robotics</u>: The vision specifically calls for robotic missions to serve as the trailblazers. As amply demonstrated by the Mars Exploration Rovers “Spirit” and “Opportunity” and the armada of space observatories and planetary probes, robots serve us well and provide excellent science returns. But the President’s vision recognizes the need for human oversight of a next phase of much more complicated missions than is achievable with today’s remote sensing or limited

rovers. Enabling this new paradigm of exploration will require more sophisticated robotic capabilities and an exquisite interface between robots and humans.

Power and Communications: The next steps in exploration, which include *in situ* robotic operations, sample return missions, and human presence, will require much greater communication bandwidth and power systems. NASA is currently pushing optical communications for planetary missions that would in principle improve data transfer rates to Earth by orders of magnitude. Imagine the advantage, not to mention the excitement, of watching high resolution video—rather than today's still pictures—from a rover traveling through the Martian landscape. Also integral to the exploration vision is enabling much greater power to operate the instruments and tools.   Advanced nuclear power systems being developed have the capability to operate at all latitudes on Mars and deeper in the Solar System where the solar flux is feeble.

Maintaining Strong Science

The changes to the NASA budget reflect the new priorities derived from the vision as well as the fiscal realities. Much of the $11 billion reprioritized within the FY2005-FY2009 budget comes from discontinuing the launch technology program, savings derived from the Shuttle retirement, and reprioritizing research on the International Space Station. The rest of the savings comes from slowing down a few missions and keeping the spending rate constant for other programs.

In this budget, Space Science continues to be robust. The vision specifically calls for a new series of robotic exploration missions to the Moon and Mars. The outer planets will continue to be a research priority with the Jupiter Icy Moons Orbiter (JIMO) -- designed for long-duration, in-depth study of 3 Jovian moons that appear to contain significant water ice. And the budget includes a mission to Pluto – the only planet in our Solar System left to be visited by robotic probes.

The Sun-Earth Connection research remains important to NASA and the Nation. Despite the stretch-out of the Solar Terrestrial Probes awards, this program -- and all others in NASA's Sun-Earth Connection theme -- is scheduled to continue. The Sun-Earth Connection research budget rises by $17 million in 2005 from the 2004 level and will remain at roughly the $200-million level for the next several years. The 2005 budget therefore enables NASA to continue to pursue its goals in solar science. In addition, Sun-Earth Connection funding is expected to grow from $746 million in 2005 to $1.05 billion in 2009, providing for the ability to begin new and exciting major solar and space physics missions.

Observatories that probe the evolution of our universe and the matter within it are among the most important instruments in science. Building upon the success of missions like the Hubble, Spitzer, WMAP, and others, a whole new generation of space observatories is being planned, each pushing the frontiers of new wavelengths and resolutions to peer back in time toward the origins of the universe; observe potentially cataclysmic events; and to identify and study extra-solar planetary systems. The FY2005 budget maintains the Webb telescope's scheduled 2011 launch date. Funding is provided to cover launch delays to the Gamma-ray Large Area Space Telescope (GLAST), the Gravity Probe B, Swift and Herschel-Planck. Pushing the frontier of space observations even further are Con-X and the Laser Interferometer Space Antenna (LISA) which are maintained in the budget but slowed down slightly, which will help NASA to retire some of the technical risk associated with these pioneering missions.

NASA's Earth Science Enterprise has been, and will continue to be, the largest contributor to the interagency Climate Change Science Program (CCSP). The President's Budget requests nearly $1.5 billion for NASA's Earth Science programs. These funds support new missions to measure ocean salinity, assess carbon dioxide concentration, and monitor aerosol concentrations in-line with the Climate Change Strategic Plan released this past summer. In addition, funds are provided to ensure the continuity of Landsat data as well as test key sensors on the next-generation of operational Polar orbiting satellites, both of which are important components of our Earth observing infrastructure. In a few instances missions are deferred and/or canceled where the absence of specific data sets would not cause undue harm to scientific progress.

The President's FY2005 budget supports the NASA Aeronautics Blueprint with a request for $919.2 M. This maintains the funding level for Aeronautics that was in the President's FY2004 budget plan. The presence of FY2004 earmarks in the budget numbers creates the impression that reductions have been made to content, which is not the case. The Blueprint identifies challenges facing aviation today and describes a vision of technology advances that will help solve these challenges. These advances will also create a whole new level of system performance and revolutionize civil and military aviation. The proposed FY2005 budget request includes the development of the highest priority (safety/security, noise, and emissions) technologies and directly supports the vision espoused by the Blueprint. To further emphasize the priority of Aeronautics, a new NASA enterprise specifically focused on Aeronautics has been created.

Benefits to Science and Technology

In addition to the programs described above, two additional benefits for science and technology are anticipated from the President's vision. First, the technology development necessary to carry out this vision will accelerate advances in robotics, autonomous and fault tolerant systems, human-machine interface, materials, life support systems, and spur novel applications of nanotechnology and micro-devices. All of these advances, while pushing the frontiers of space, are likely to spur new industries and applications that will improve life on Earth.

Second, articulating the human journey into the cosmos, with clear and challenging milestones, will inspire future generations of young people to study math, science, and engineering. A framework and a vision for a *sustainable* exploration, coupled with intellectually stimulating problems, is a substantial asset in the continuing campaign to spark interest in science and technology in each new generation.

Conclusion

This vision has consequences. It implies that we optimize not for a single mission but for the steady accumulation of technologies and capabilities that provide a base for multiple operations. It emphasizes the role of robotics, of ground-based research, and of system thinking. And it places the International Space Station in a larger context of preparation for the journey of exploration.

The vision articulates the purpose for humans in space. We have a vigorous and highly productive program of non-human space operations for scientific, military, and commercial purposes. These "robotic" missions have their own strong justification, and will contribute to the achievement of the vision for humans. The philosophy of going step by step, preparing for the future on a broad front, introduces human capabilities only as appropriate, keeping in mind that the ultimate goal is to permit humans to operate routinely on missions where they are needed.

The vision is good for science. Enabling this vision will lead to a greater understanding of our place in the universe, the history of the solar system, and push technology on many fronts that are important to the economic security of this Nation. It will also open up new possibilities for future science missions that have more aggressive goals. And it prioritizes and maintains a healthy portfolio of research in space and aeronautics.

Hubble Space Telescope

In your invitation to testify at today's hearing you asked me to describe the contributions to science made by the Hubble Space Telescope and to assess what would be lost if the Hubble ceased to function earlier than had been planned. And you asked how to weigh these losses against the potential benefits of other activities under the new initiative.

Let me start by stating clearly my understanding that the decision to cancel the SM-4 servicing mission to the Hubble Space Telescope was based upon NASA’s assessment of the safety and recommendations made by the Columbia Accident Investigation Board. We fully support NASA’s concerns about safety and we support the Administrator's action in asking Admiral Gehman to review this matter and offer his unique perspective.

Since its launch in 1990 (and subsequent repair mission), "the Hubble" has provided spectacular data that has improved our understanding of the cosmos. As the authors of the 2001 National Research Council “*Astronomy and Astrophysics in the New Millennium*" put it "The Hubble Space Telescope has arguably had a greater impact on astronomy than any instrument since the original astronomical telescope of Galileo." The Hubble was launched with a planned 15 year mission and assumed service missions approximately every 3 years. Over the past decade, servicing missions have made repairs, upgraded instruments, and re-boosted the telescope to ensure a continuing stream of valuable data. The SM-4 mission was designed to replace the gyros that stabilize the telescope, repair some thermal insulation, replace the Fine Guidance Sensor, replace the batteries, and to install two new instruments (Cosmic Origins Spectrograph and Wide Field Camera-3). It was estimated that the servicing mission would have added 4-5 years of life to the Hubble.

In the 14 years since Hubble was launched, tremendous progress has been made in improving the quality of ground based telescopes. Using adaptive optics – that is compensating for atmospheric turbulence which degrades the resolution of the image – ground based telescopes are now capable of resolution competitive with, and in some instances better than, the Hubble in the longer wavelengths (near-infrared) -- albeit for objects with good contrast and over smaller fields-of-view. Over the next few years, advanced adaptive optics techniques are being planned for the next generation of ground based observatories, improving both the resolution and fields of view.

In its assessment of ultraviolet and optical astronomy from space, the National Research Council report did not recommend new missions in the Hubble wavelength regime for three reasons: "First, many of the key science opportunities [in this regime] are predominantly in the infra-red" (the wavelength region covered by the recently launched Spitzer telescope). "Second, the IR region has been studied much less than the optical region, so the potential for discovery is much greater. [Third] much of the important optical astronomy can be done from the ground." The committee wrote its report assuming the SM-4 service mission would take place, but its statements regarding the evolving role of the Hubble relative to other priorities are important in the present discussion about risk versus benefits.

There are some things the Hubble can do that ground based telescopes cannot. It can stare at select regions of the sky for extremely long periods of time. It can return to anyplace in the sky over time and add up or 'stack' exposures. Ground-based observatories can do this same 'stacking', but to a much more limited extent because of the variations introduced by the atmosphere. In the vast majority of cases ground-based imaging observations are limited to a single night's length. Where they overlap in wavelength coverage, larger ground-based telescopes collect light faster than Hubble so similar science can be done in less time.

The next generation Webb Space Telescope – Hubble's replacement – is being designed with about 6 times the collecting area, which should allow for study of fainter objects. The Webb is also being designed to be optimized in wavelengths that are not accessible from the ground, providing data that can not be collected from a platform other than one in space.

If it is serviced, I have no doubt that the Hubble would continue to provide world-class scientific data and be used to further refine our understanding of the Universe. But the safety issues can not be ignored, and they must be considered not only with respect to the Hubble capability, but also the ever increasing capability of visible ground-based telescopes combined with the exciting next-generation space observatories being built.

As stated earlier, I commend the NASA Administrator for taking an objective look at this problem and for soliciting the review by Admiral Gehman.