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Statement of
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Committee on Science and Technology
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Chairwoman Giffords and other Members of the Subcommittee, thank you for the opportunity to appear today to discuss NASA's technology development programs. As a research and development Agency, a balanced portfolio of R&D at NASA serves the Nation directly and is a catalyst for innovation as well. My testimony will address how NASA technology is relevant to the Nation and the communities that comprise it, and how that might be strengthened.

In your letter inviting me to testify, you asked that I address a number of specific questions related to technology development at NASA. My statement will address those questions, as well as provide additional context.

NASA has been at the forefront of aeronautics research and development since the early 20th Century, and space technology since the mid 20th Century. During that time, NASA and its predecessor organization, the National Advisory Committee for Aeronautics (NACA), balanced near-term missions and long-term research to benefit the Nation and the world. Over the past few years, however, NASA has prioritized short-term mission needs over long-term research. Much new technology in terms of materials, systems, components, and software that benefits our missions as well as others is developed through the NASA Mission Directorates, the Innovative Partnerships Program, and the Centers. The NASA mission focus also serves technology development by focusing activities on technologies needed to address current and future problems as well as providing the test bed for demonstrating these new technologies.

NASA Response to Recent External Reviews

Several recent external reviews have addressed the issues of innovation and technology development at NASA, with a strikingly common set of themes. Although the final report is still pending, the Summary Report of the Review of U.S. Human Space Flight Plans Committee strongly endorsed increased focus on innovative technologies and approaches to achieving broadly defined NASA and national goals. This technology and innovation focus was included in all new program options suggested by the Committee in its Summary Report. The recently released National Research Council (NRC) report, *"America's Future in Space,"* specifically calls for NASA to create a capability to develop game changing approaches to National challenges. This recommendation is similar to one made by the Aldridge commission in 2004. Finally, the recent NRC report *"Fostering Visions for the Future: A Review of the NASA Institute for Advanced Concepts"* is also highly relevant. It suggests re-creating an early stage innovation engine like the NASA Institute for Advanced Concepts (NIAC). These NRC reports especially emphasize the need for some organizational independence from the

mission-focused parts of the agency in order to provide stability to the investment and a more risk-tolerant environment to foster innovation. They recommend a broad reach, across disciplines and organizations, to ensure the best ideas are brought forth and supported. All suggest that failure to invest in technology and innovation puts the Agency's future viability at great risk.

In recognition of the need to rebalance near-term mission and far-term technology and innovation investments, the Agency chartered an internal study team to investigate the barriers to NASA innovation and make suggestions for approaches to address these barriers. The study team had participation from across NASA Mission Directorates, Centers, and Offices.

The barriers to innovation identified by our internal study team agree with many of the findings of the external committee reports with respect to both the overall shortfall and the focus. NASA's investments in innovation and technology have been focused on the near term, especially in the space-related disciplines. In addition, the Agency could do a better job in many areas of engaging partners from across academia, industry and other Government agencies in its technology development efforts. This would allow both the most innovative ideas to be brought forward, and the broadest application of NASA-supported capabilities to address broader National needs in areas of high priority to the Nation.

Also recognized in multiple studies is the importance of capabilities for taking technology from the lab bench to demonstration for flight use. This is an area which has traditionally been left to flight projects which typically cannot assume the risk and/or cost for technologies that are not enabling the mission, and requires a diversity of approaches to ensure that the needs of the ultimate user community are fully addressed. Driven by the specifics of the technology and the target use, successful approaches can be as simple as environmental and life testing or as complex as demonstration packages on host missions or dedicated flight demonstrations.

NASA is planning to use an integrated portfolio management approach, balancing needs from across the Agency, balancing near-term and long-term investments, and ensuring that resources are appropriately leveraged across the various mission areas to secure the maximum impact for our investments. NASA will examine reward structures and culture to encourage more risk-taking in innovation activities. Although our "failure is not an option" ethic is essential in the spaceflight arena where lives are at stake, innovation demands pushing the envelope, occasionally failing, and learning from those failures to drive game-changing solutions to NASA's grand challenges.

NASA Missions Require Technology to Address Extreme Conditions

NASA's missions require technology beyond state-of-the-art, where hardware and systems meet the extreme conditions of space and high-performance aeronautics. The environments in which humans, spacecraft, and equipment must work pose unique challenges, prompting development of unique capabilities.

Science missions face a variety of extreme environments, with over 90 spacecraft operating or planned to operate throughout the solar system and beyond. For example, the Juno spacecraft being prepared for launch in 2011 must survive a five-year journey to Jupiter and operate for about a year on solar power in an area where there is 25 times less sunlight than at Earth and at temperatures that may approach -275 degrees Fahrenheit, requiring some of the most hardy and efficient solar arrays ever built. The James Webb Space Telescope, a 6.5-meter (~21 feet) space telescope, will need to operate at about 35 degrees above absolute zero or -396 degrees Fahrenheit. Another example is Solar Probe Plus, which is planned to launch no later than 2018 and will operate just 3.7 million miles above the Sun's "surface," some seven times closer than any spacecraft has come before. At its closest approach, Solar Probe Plus' shield must withstand temperatures up to 2,600 degrees Fahrenheit, while allowing the payload of science instruments to operate at or near room temperature.

While more protected inside the Earth's magnetic field, NASA and its partners must enable humans to live and conduct experiments in space on the International Space Station -- a 500 metric ton, football-field sized, permanently crewed, full-service space platform operating at an altitude of 350 kilometers in a 51.6 degree inclination to the Earth's equator. Research for flight beyond low-Earth orbit must enable long-term human health in micro-gravity, under varying radiation conditions, with remote medical assistance. Lastly, although operating on Earth, aeronautics research must make air vehicle concepts, such as vertical lift and supersonic flight practical for commercial use, and enable significant increases in air transportation capacity while still protecting the environment, ensuring safety, dramatically improving efficiency, and revolutionizing the flow of air traffic.

Relevance of Mission Technology to other Sectors

NASA technology development over the last decade has by and large focused on the needs of the missions. This situation raised the importance of infusion into NASA missions of technology developed jointly in partnerships with industry, academia, other Federal agencies, and other external entities. Interestingly, the advanced nature of NASA technology, combined with the emphasis on partnering, served to increase the likelihood of additional relevance to other market sectors and communities.

As an example, the Science Mission Directorate (SMD) partners with the Small Business Innovative Research (SBIR) program to develop key technologies for the Mars Science Laboratory (MSL). SMD worked with Microwave Power Technology of Campbell, California, to develop a small-format Carbon Nanotube Field Emission cathode (CNTFE) X-ray tube for the Chemistry & Mineralogy instrument on MSL. While a tungsten cathode was ultimately baselined for the flight tube, the form, fit and function of the flight tube was derived from this SBIR project.

The Innovative Partnerships Program works through its offices at all ten field centers to facilitate the transfer of Agency-developed technologies for commercial application and other public benefits. Licensing, together with a wide portfolio of innovative partnering mechanisms, results in commercial products that contribute to the development of services and technologies in health and medicine, transportation, public safety, consumer goods, agriculture, environmental resources, computer technology, manufacturing, and other key industrial sectors. Each year, NASA documents 40-50 of the best current examples of how mission technology has yielded public benefit in the annual *Spinoff* publication.

Game-Changing or Paradigm Shifting Solutions

Due to the near-term program focus of NASA's current technology programs, the likelihood of developing and infusing mission "game-changing" technology is reduced. Still, with clear challenges on the demand-side, significant emphasis on partnering, and continuing programs with universities, such paradigm-shifting solutions do nonetheless occur, often with additional applicability outside of NASA.

NASA's Exploration Systems Mission Directorate (ESMD) is developing very high-performance lithium ion battery cells that significantly exceed current state-of-the-art, and are highly reliable, self-contained Proton Exchange Membrane (PEM) regenerative fuel cells. Current automotive fuel cells are not regenerative and consume oxygen from the atmosphere plus hydrogen from onboard storage tanks to generate electricity. The PEM regenerative cell uses electricity to convert water into hydrogen and oxygen stored in tanks that can later be reconverted back into electricity. In space applications, such advances in energy storage systems would be useful to human explorers on a terrestrial surface where there is a decreased ability to create solar energy. This technology also could be useful to farms and businesses that need large kilowatt power generated during off-peak hours on the grid or from other sources.

The NASA partnership with the Defense Advanced Research Projects Agency (DARPA), industry, universities, the Internet Research Task Force and several international space agencies has created the new technology of "Delay Tolerant Networking" (DTN), which enables the extension of the Earth's Internet to sustain communications over interplanetary distances -- for example to and from the Moon and Mars. This technology has been spun-off to enable many new terrestrial applications where the Internet can be extended into highly stressed communications environments, such as remote villages, battery-powered sensor webs and undersea communications. Military applications of DTN are substantial, allowing the dissemination of critical battlefield situational awareness information into areas where communications networks are sparse and subject to a high degree of disruption.

NASA, in partnership with the Air Force Research Lab and Boeing, successfully completed flight experiments of the X–48B Blended Wing Body (BWB) advanced aircraft at the NASA Dryden Flight Research Center. The BWB is a hybrid configuration combining the best attributes of a conventional "tube-and-wing" aircraft with a flying wing. It has the potential to meet expected future Next Generation Air Transportation System requirements for low noise, low emissions, and high efficiency. It is the first time a dynamically scaled BWB was flown. The experiments demonstrated the basic flying qualities of the X–48B and the effectiveness of the on-board flight control system. NASA is continuing to research the BWB concept along with other unique configurations in order to enable future vehicles that profoundly improve the efficiency and capabilities of air transportation.

Other examples include optical communications, in-space propulsion, and tools and techniques such as modeling and simulation for Earth science, or shell buckling test facility and analysis for significantly reduced weight and cost of next-generation launch vehicles. A program similar to the NASA Institute for Advanced Concepts (NIAC) would be valuable in identifying other game changing technologies.

Technology Innovation and Leveraging

The NASA Innovation Partnerships Program (IPP) continues to pioneer the use of non-traditional approaches such as the Centennial Challenges Program which uses incentive prizes to spark innovation and drive technology to meet the Agency's high-performance technology challenges. A key result of the Centennial Challenges competitions is the demonstration of dramatic efficiencies in the research and development process when compared with typical industry practices.

The Lunar Lander Challenge requires that teams build and fly a reusable rocket-powered vehicle that can mimic a robotic flight to and from the surface of the moon, but in an Earth-based demonstration. Teams must design, build and test these vehicles without any government support or funding. The return on investment with an incentive prize can be enormous, and this contest has yielded working prototypes from multiple sources. Two teams have successfully flown vehicles and qualified for prizes and others are planning to fly later this month. Additional NASA partnerships and commercial ventures have resulted from this incentive prize.

Another example is the Regolith Excavation Challenge which recently took place at Moffett Field in California. The goal was to use either a teleoperated or autonomous device to excavate at least 150 kilograms of simulated lunar regolith within thirty minutes. Nineteen teams competed with working robots, and three teams met the minimum requirements and claimed prize money, with the winning team from Worcester Polytechnic Institute excavating over 500 kilograms. The Regolith Excavation Challenge is important because future lunar astronauts may "live off the land" by excavating lunar regolith and extracting useful materials from it, such as oxygen and even recently discovered water molecules that seem to be bound within lunar topsoil. The competing teams advanced the technology necessary for this kind of operation without a lot of investment from NASA.

Additionally, the NASA IPP Partnership Seed Fund enhances the Agency's ability to meet mission technology goals by providing seed funding to overcome technical barriers with cost-shared, joint-development partnerships

between non-NASA partners, NASA Programs and Projects and NASA Centers. Seed Fund projects have highly leveraged NASA's investment and resulted in many important technologies including: two different lunar tire designs from partnerships with Michelin and Goodyear; a prototype inflatable lunar habitat that was field tested in Antarctica in partnership with the National Science Foundation and ILC Dover; and testing of alternative fuels for aircraft engines in partnership with Pratt & Whitney and the Air Force Research Laboratory.

Coordination and Collaboration with Partners

NASA and its partners leverage mutual interest in many technologies across the missions. For example, ESMD has a research portfolio related to its Exploration Technology Development Program and Human Research Program that will benefit future space explorers as well as other organizations on Earth. NASA is funding approximately 250 investigations related to ISS research and exploration that include approximately 80 active flight investigations. Investigators in the life sciences do not depend solely on NASA for the totality of their research funding. Most NASA funded investigators receive funding from other agencies as well, including the National Science Foundation, the National Institute of Health, the Department of Defense, and the Department of Energy for related research efforts. In fact, NASA often works directly with these agencies through working groups and Space Act Agreements. The ESMD has nearly 100 agreements in the form of Memoranda of Agreement and Understanding with other Federal agencies and international partners. The synergy between these Federal agencies is clear and coordinated.

In FY2008, about half of SMD's investment in technology programs was in mission-specific technology developments tied to NASA flight missions. The remainder was for Principal Investigator-led research investigations, suborbital research programs (which are often used to test new technologies and instruments in suborbital context before they are manifested on space-borne missions), and a dedicated Earth science technology program to enable the highest priority missions called for in the National Research Council Earth Science Decadal Survey. These latter investments supported 21 instrument incubation projects that are broadly aimed at addressing science measurement objectives put forward in the Earth Science Decadal Survey. These new projects include a carbon dioxide (CO_2) laser sounder for the Active Sensing of CO_2 Emission over Nights, Days, and Seasons (ASENDS) mission (a Tier 2 mission in the decadal survey), a multi-parameter atmospheric profiling radar for the Aerosol/Cloud/Ecocsystems (ACE) mission (a Tier 2 mission) and a laser ranging frequency stabilization subsystem for the follow-on Gravity Recovery and Climate Experiment (GRACE-II) mission (a Tier 3 mission). These Earth Science measurements will enable us to better understand how the Earth's climate, water cycle, carbon cycle, and living beings interact and how they impact society.

NASA also works with industry partners who can adapt these technologies to serve broader societal needs. Perhaps the world's most famous telescope, the Hubble Space Telescope has given us more than close-up views of our galaxy; it has served as a technological engine for various industries. Technologies developed for Hubble have enabled surgeons to perform micro-invasive arthroscopic surgery with increased precision, made breast biopsies less invasive and more accurate using imaging technology, and led to optimized semiconductor manufacturing through precision optics and advanced scheduling software.

As NASA transitions the ISS from the assembly phase to the full utilization phase, the ISS will be operated as a U.S. National Laboratory and thus made available to other U.S. government agencies, academic institutions, private firms and non-profit organizations. At that stage, the research benefits will extend beyond NASA and begin accruing in areas related to U.S. national needs in such areas as improvement in human health and energy systems research.

Improvement in human health is the mission of the National Institute of Health (NIH). The NIH entered into a Memorandum of Understanding with NASA to use the ISS for research. In Spring 2009, NIH issued a three-year rolling announcement for research grants in areas including: (1) cancer; (2) heart, lung and blood disorders; (3)

aging; (4) arthritis and musculoskeletal and skin diseases; (5) biomedical imaging and bioengineering; (6) child health and human development; and, (7) neurological disorders and stroke. Research is scheduled to begin by the end of 2010.

In preparation for full utilization phase of the Space Station, NASA has entered into agreements with private firms such as Astrogenetix, Inc. as pathfinders for the future. Based on basic research funded by NASA under prior grants, the company is now pursing vaccine development under microgravity conditions. A vaccine target for salmonella-induced food poisoning was discovered in 2009, and the company is seeking investigational new drug status from the U.S. Food and Drug Administration. Follow-on experiments are underway on a variety of bacterial pathogens, including Methicillin Resistant Staphylococcus Aureas (MRSA), which is responsible for almost 20,000 human deaths per year.

The NASA Aeronautics Research Mission Directorate (ARMD) has a research portfolio, predominately focused on long-term foundational research, which is both comprehensive and coordinated in order to make substantial improvements to the future air transportation system. There is strong alignment of NASA's aeronautics research portfolio with the National Aeronautics Research and Development Policy and Plan and the high level goals of the National Research Council's Decadal Survey on Civil Aeronautics (2006), which identify short and long-term strategic aeronautics research and technology goals for our Nation. A good example is the development of new vehicle concepts that are much more efficient and exhibit dramatic reductions of emissions and noise impacts. NASA fundamental research has paved the way for concepts such as hybrid wing body vehicles that are quite different from the "tube and wing" aircraft that are familiar today. Research includes novel propulsion systems and support for the creation of new alternative fuels that show promise for even more improved environmentally friendly performance.

Similar to the other Mission Directorates, ARMD utilizes a variety of mechanisms to engage academia and industry, including industry working groups and technical interchange meetings at the program and project level, Space Act Agreements for cooperative partnerships with industry, and the NASA Research Announcement (NRA) process that provides full and open competition for the best and most promising research ideas. Cooperative partnerships with industry consortia result in significant leveraging of resources for all partners and can provide opportunities to test the value of component-technology advances in full system-level contexts. All research results, whether generated by NASA internally or by its partners through the NRA, are openly disseminated through archival publications and conference proceedings as well as NASA publications to benefit the broad U.S. aeronautics community while ensuring the dissemination policy is consistent with National security and foreign policy guidelines.

NASA aeronautics research is conducted in a highly collaborative environment among Federal agencies. The National Aeronautics Research and Development Policy and Plan provides the strategic framework that facilitates coordination among the Federal agencies. NASA builds upon this framework to coordinate with other Agencies when appropriate. For example, to facilitate the transition of advanced ideas and technologies into the aircraft fleet, NASA is partnering with the Federal Aviation Administration's Continuous Low Emissions, Energy and Noise (CLEEN) program to guide efforts to mature technologies that have already shown promise to the point where they can be adopted by the current and future aircraft fleet. Additionally, NASA and the U.S. Air Force have established an Executive Research Council that meets at least twice a year to ensure close coordination and collaboration. Another example of a significant partnership effort involving NASA that spans multiple government and commercial organizations is the Commercial Aviation Safety Team, which was recently honored with the prestigious Collier Trophy for reducing fatal air transport accidents by 83 percent in a decade.

Response to NASA Authorization Act Direction Related to Technology Development

With regard to NASA's response to the provisions in authorization legislation directing greater commitment to robust technology research and development initiatives in aeronautics, exploration, and space and Earth sciences, several examples stand out.

NASA has responded to authorization language pertaining to further investment in the development of technologies related to environmentally friendly aircraft by formulating the new Environmentally Responsible Aviation Project under the new Integrated Systems Research Program in order to build on recent developments in the existing research programs. This new effort will include further technology advancement and research in conjunction with academic and commercial partners. Work is also ongoing to ensure that new vehicles are accurately modeled in air traffic management simulations, but further research can improve the fidelity of these simulations to facilitate the development of new procedures, processes and techniques for managing air traffic.

While NASA-sponsored investigations on the Space Station are currently focused largely on enabling future long-duration human space exploration missions, Congress designated the U.S. portion of the Space Station as a National Laboratory making its facilities available to other Federal agencies and private entities. These collaborations are well underway.

In addition to non-mission focused technology activities previously mentioned, NASA's Science program continues to emphasize the role of cross-cutting technologies in the annual competitions for its major technology development programs such as the Planetary Instrument Definition and Development Program and the Earth Science Instrument Incubator Program. We have already conducted a review to determine the highest-priority, cross-cutting technologies, and we will use those priorities in making future selection decisions for technologies. Key cross-cutting technologies of interest to science include sensors (e.g., Light Detection and Ranging LIDARs, long-life lasers, *in situ* sensors and tools), information systems (e.g., data processing, large-scale numerical simulation/modeling, and data management, mining and visualization tools), platforms (e.g., photovoltaic and radioisotope power systems, chemical and electrical propulsion, radiation-hardened computer processors, low power/low mass application-specific integrated circuits), suborbital technologies (including sounding rockets, balloons, and unmanned aircraft systems), large lightweight deployable structures (especially telescopes and antennas), and integrated modeling techniques (e.g., structural, optical, thermal, and instrument models that share the same databases).

Conclusion

The National Academy of Sciences issued a warning in its report *Rising Above the Gathering Storm*: "The United States faces an enormous challenge because of the disparity it faces in labor costs. Science and technology provide the opportunity to overcome that disparity by creating scientists and engineers with the ability to create entire new industries – much as has been done in the past." The Academy recommended increasing America's talent pool by vastly improving K-12 mathematics and science education; strengthening the Nation's commitment to long-term basic research; developing top students, scientists, and engineers; and, ensuring that the United States is the premier nation in the world for innovation.

Most assuredly, NASA can contribute. As the Agency pursues demanding missions in Earth science and climate research, human and robotic exploration, astronomy and astrophysics, solar physics, and aeronautics, NASA must answer several fundamental questions: Is there water on Mars? Can humans live for extended periods in space, and if so can they live on the resources they find? What can we do to inform choices on mitigating and adapting to global change? Are there other solar systems like ours in the universe? As noted earlier, the missions created to answer those questions utilize specialized hardware that must endure extreme environmental conditions and demand functionality beyond that required for Earth-based applications.

The NASA mission focus and ability to develop technology from infancy to application provides an extraordinary forcing function for innovation. The Agency's technology challenges are multidimensional, requiring multidisciplinary solutions. Shared with the academic community, these challenges help prepare graduate students by enabling them to work on real-world challenges early in their careers. NASA technology lends itself to practical collaboration across government, academia, and industry. In addition, technology development linked to exciting NASA missions can provide a low risk avenue to encourage K-12 students. Finally, most NASA projects require large-scale system engineering. Addressing challenges with these characteristics has a powerful galvanizing effect on educational institutions and students, and thus on the aerospace industry, other industries, and on NASA.

Our Nation has made great progress throughout its history because of the enormously difficult challenges it has encountered. The grand challenge to build an intercontinental railway, or to land a man on the Moon and return him safely to the Earth, not only utilized our best talent, but also created new technologies, inspired generations to pursue challenging goals, created new industries, and ultimately improved our country and the world. Similar opportunities are in front of us now.

Chairwoman Giffords, I would be happy to respond to any questions you or the other Members of the Subcommittee may have.