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Statement of

Dr. Jaiwon Shin
Associate Administrator for Aeronautics Research
National Aeronautics and Space Administration

before the

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Mr. Chairman and Members of the Subcommittee, thank you for this opportunity to testify on NASA's Aeronautics Research program and the research and development challenges in aeronautics.

NASA's Aeronautics research is making air travel cleaner, safer, and more efficient. NASA conducts transformative aeronautics research for long-term leadership, engages in collaborative partnerships to achieve real near- to mid-term results, and infuses high impact research advancements from non-aerospace fields to benefit the aviation community. NASA's aeronautics research continues to play a vital leadership role in air travel and commerce by enabling game-changing technologies and innovation that allow the U.S. aviation industry to continue to grow and maintain global competitiveness. NASA's Aeronautics Research Mission Directorate (ARMD) portfolio is fully aligned with our strategic vision, focusing on the most critical technical challenges to address a growing demand for mobility, severe challenges to sustainability of energy and the environment, and technology advances in information, communications, and automation technologies.

Importance of Aviation

Today's air transportation system is an integral part of the U.S. and global economies. It is the primary mechanism for connecting countries across the world through mobility of populations and mobility of goods and services.

Aviation accounts for more than $1.5 trillion of total U.S. economic activity annually and is one of the few industries that generates a positive trade balance, $78.3 billion in 2014 alone. The aviation industry supports more than 11.8 million direct and indirect jobs, including more than one million high-quality manufacturing jobs.

The overarching impacts of aviation and the air transportation system can be felt right down to the individual; just about every product produced and purchased today has been touched by aviation in some way. Air transportation of freight valued at more than $1.6 trillion occurs every year. U.S. airlines carried more than 761 million passengers in 2014 for both domestic and international flights. Air travelers spend more than $670.8 billion per year for business and personal travel. In short, the U.S. aviation industry is critical to both the health of the economy and the functioning of our global society.

National Level Challenges

Market factors such as those discussed above point to several key national level challenges facing the aviation industry:

A primary challenge is to ensure that our system continues to meet our demanding expectations of safety, even as new technologies find their way into the system and as air transportation grows around the world. This means changing the way we think about safety so our design methods and certification processes match up with the new technologies entering the system—at the same time as we tackle continuing and emerging safety concerns.

Another important challenge is to improve mobility, both in terms of increasing capacity and saving fuel. This means using less fuel tomorrow to carry passengers and packages than we use to carry them the same distances today, by flying more efficient routes and using more fuel efficient aircraft. It also means increasing the number of flights which can be handled in existing airspace.

A related challenge is to limit the environmental footprint of aviation, which is a top tier concern related to maintaining U.S. industry economic health and avoidance of constraints on operations. Reduced fuel consumption directly reduces greenhouse gas emissions and pollution, but that is not enough. In addition to reducing the amount of fuel used, we must simultaneously reduce the emissions from the fuel that is used and minimize aircraft noise near increasingly busy airports. Translated into numbers, the challenge is to develop technology by 2020 to cut fuel consumption in half, reduce the area of objectionable noise around airports to one sixth of what it is today, and reduce Nitrogen Oxides emissions to half that of the newest aircraft flying today.

The critical challenge—and opportunity—facing manufacturers and airlines is to remain competitive in this growing and increasingly complex market through infusion of new technology. Aviation and aeronautics can enable whole new markets that can spur new avenues of economic growth and job creation. This is not limited to advances in traditional markets—new aircraft and technologies such as Unmanned Aircraft Systems or UAS, may bring radical changes to the way we think about and use aviation.

Research conducted by NASA's Aeronautics Research Mission Directorate has directly benefited today's air transportation system, aviation industry, and the passengers and businesses who rely on aviation every day. The tools and technologies that resulted from this research increased the capacity and improved the efficiency, safety, and environmental compatibility of the air transportation system. Just as our aeronautics research and development investments over the last 100 years have shaped the aviation system of today, our current portfolio is setting the foundation for the next 100 years of aviation innovation.

NASA Strategic Vision

NASA aeronautics guides its efforts with a compelling new strategic vision. This strategy is the culmination of a multi-year effort that included gathering industry and other Government agencies' inputs, systems analysis of environmental and market trends, and the identification of societal mega-drivers. The trend analysis indicated that NASA could best contribute to the Nation's future societal and economic vitality by focusing on efforts that are responsive to a growing demand for mobility, major challenges for energy efficiency and environmental sustainability, and convergence between traditional aeronautical disciplines and rapid technology advances in energy systems, additive manufacturing, and cyber-physical systems. Our investment strategy is outlined in the recently published Strategic Implementation Plan, encompassing our vision for aeronautical research aimed at the next 25 years and beyond.

ARMD's research activities center around six strategic research thrusts:

- Thrust 1: Safe, efficient growth in global operations;
- Thrust 2: Innovation in commercial supersonic aircraft;
- Thrust 3: Ultra-efficient commercial vehicles;
- Thrust 4: Transition to low-carbon propulsion;
- Thrust 5: Real-time, system-wide safety assurance; and,
- Thrust 6: Assured autonomy for aviation transformation.

Each strategic thrust is designed to address an important area of research and technology development that will further U.S. leadership in the aviation industry and enhance safe, sustainable global mobility. NASA's research is performed with an emphasis on multi-disciplinary collaboration focused on the critical, integrated challenges (aligned to the six research thrusts). Together, these research thrusts combine to enable safe, sustainable growth in the overall global aviation system, while pioneering transformative capabilities that will create game-changing opportunities.

To most effectively manage the research needed to address these strategic thrusts, in FY15 NASA has restructured its research programs to achieve three specific goals.

The first goal is to pursue innovative solutions aligned to the strategic thrusts. To do this, NASA has formed three mission programs. They are the Airspace Operations and Safety Program, the Advanced Air Vehicles Program, and the Integrated Aviation Systems Program. Aviation safety research is being directly integrated into the other NASA aeronautics research programs in recognition of the importance of safety considerations in all aspects of our research program. The three mission programs will clearly define the most compelling technical challenges facing the aviation industry, and retire these challenges in a time frame that is supported by the stakeholders and required by NASA's customers.

The second goal is to incentivize multi-disciplinary convergent research. This goal led to the formation of the Transformative Aeronautics Concepts Program. This program will allow for a flexible and organic environment for NASA researchers to develop high-risk, forward-thinking ideas to address aviation's big problems. This environment will allow for rapid demonstration of feasibility and quick turnover of ideas.

The third goal is to enable greater workforce and institutional agility and flexibility. To do this, the Aeronautics Test Program has been integrated into the mission programs. This will embed the flight and ground research into the performing projects to integrate all research phases and to ultimately allow for expanded flight opportunities. It will also enable more agile research practices that combine high-fidelity simulation, ground testing, and flight research.

FY 2015 is a year of transition for NASA Aeronautics to complete this alignment of our Technical Challenges with our strategic research thrusts. Much of the technical content in FY 2014 is continuing in the new program structure with a sharper focus toward achieving timely and compelling impacts to the six strategic thrust areas. We are improving our research management practices to enable the agility and flexibility we desire, while ensuring sound technical management and delivery of results to our stakeholders. Our vision sets us on a course to conduct more effective long term planning, aligning resources and capabilities with a long term vision for transformative changes in aviation.

Aeronautics Research Mission Directorate (ARMD) Programs

Business as usual is not going to guarantee the United States' pre-eminence in the global market, nor will it enable us to meet these challenges. We must stay with our proven formula of leadership through technological superiority. NASA Aeronautics has a unique and important role in that formula. Long-term aeronautics research has long provided the basis for new concepts leading to industry innovation and societal benefits. ARMD will continue its role of undertaking research and development that falls outside the scale, risk, and payback criteria that govern commercial investments.

The *Airspace Operations and Safety Program* develops and explores fundamental concepts, algorithms, and technologies to increase throughput and efficiency of the National Airspace System (NAS) safely. The program works in close partnership with the FAA and the aviation community to enable and extend the benefits of NextGen, the Nation's program for modernizing and transforming the NAS to meet evolving user needs. The program is on the leading edge of research into increasingly autonomous aviation systems, including innovation in the management of UAS traffic and other novel aviation vehicles. The program is also pioneering the real-time integration and analysis of data to support system-wide safety assurance, enabling proactive and prognostic aviation safety assurance.

The *Advanced Air Vehicles Program* develops the tools, technologies, and concepts that enable new generations of civil aircraft that are safer, more energy efficient, and have a smaller environmental footprint. The program focus includes major leaps in the safety, efficiency, and environmental performance of subsonic fixed and rotary wing aircraft to meet growing long-term civil aviation needs; pioneering low-boom supersonic flight to achieve new levels of global mobility; and sustaining hypersonic competency for national needs. The program works in close partnership with academia and industry to pioneer fundamental research and to mature the most promising technologies and concepts for transition to the aviation industry. The program also works on reducing the timeline for development and certification of innovative advanced composite materials and structures. The program sustains and advances key national testing capabilities that support aeronautics research and development.

The *Integrated Aviation Systems Program* focuses on experimental flight research and the spirit of integrated, technological risk taking that can demonstrate transformative innovation. Therefore, the program complements both the Airspace Operations and Safety Program and the Advanced Air Vehicle Program by conducting research on the most promising concepts and technologies at an integrated system level. By the end of FY15, NASA will successfully complete the six-year Environmentally Responsible Aviation (ERA) project with a series of integrated technology demonstrations to demonstrate the feasibility of a suite of technologies to meet our aggressive environmental goals.

The *Transformative Aeronautics Concepts Program* cultivates multi-disciplinary, revolutionary concepts to enable aviation transformation and harnesses convergence in aeronautics and non-aeronautics technologies to create new opportunities in aviation. The program's goal is to demonstrate initial feasibility of internally and externally originated concepts to support the discovery and initial development of new, transformative solutions supporting the Aeronautics strategy. Using sharply

focused activities, the program provides flexibility for innovators to explore technology feasibility and the knowledge base for radical transformation. The program also supports research and development of major advancements in cross-cutting computational tools, methods, and single discipline technologies to advance the research capabilities of all Aeronautics programs.

Partnerships

Partnerships have been an essential part of NASA aeronautics activities since the establishment of its predecessor, the National Advisory Committee for Aeronautics, in 1915 and are based on a clear recognition of the value that's added in sharing knowledge and unique capabilities with others. Our partners include, but certainly are not limited to, other U.S. Government agencies, universities, traditional aeronautics commercial sector representatives and organizations, and foreign government agencies.

Industry partnerships in particular are critical to ensure relevance of our research and in transitioning results to the ultimate end user. Industry also is a valuable cost sharing partner that provides key skills and hardware that NASA doesn't have but is needed for the research to take place. Together our combined efforts are helping to meet the present and future challenges of a globally connected air transportation system.

Partnership in research is critical to our success. Through open competition, we solicit and fund proposals for foundational research by academia, industry, and non-profit organizations via NASA Research Announcements (NRAs) to seek the best new ideas in support of ARMD strategic goals and research objectives. NRAs provide NASA researchers access to fresh ideas, leverage our funds by fostering collaboration between government, industry and academia, and provide universities the opportunity to involve the next generation of engineers in working on today's aeronautics technical challenges. NRA results often serve to identify the "trade space" related to a particular research topic, to identify solutions to particularly difficult problems, or to assist with technology transition.

Through Space Act Agreements, we partner with large and small manufacturers to conduct fundamental research, test novel new concepts and technologies, and leverage their own investments to transition advancements from the laboratory into the field. Through Small Business Innovative Research (SBIR) contracts, we fund innovation by small businesses in foundational aeronautics disciplines in line with our portfolio.

We transfer results of fundamental and systems-level research to the aerospace community through dissemination of research results, concepts, and design methods. In some instances, companies may build on specific technologies and capabilities developed through NASA research, investing their own research and development dollars to take those last steps to become a commercialized product. In other instances, NASA provides design methods and understanding used by companies in developing new products. By maturing new technologies and validating design methods, NASA research can buy down the risk of incorporating new technologies and systems in aircraft, shortening the path through safety certification in the FAA and speeding the transition of new technologies into the fleet.

Implementing NextGen

One of our most important government partners is the Federal Aviation Administration.

Over the last several years, NASA, the FAA and the five other federal agency members of the Joint Planning and Development Office (JPDO) together defined the vision for the Next Generation Air Transportation System (NextGen) and established a roadmap to get there over the long-term. The NextGen JPDO played an important role in helping to establish a common vision for NextGen across government and industry, and coordinate development of the future NAS architecture and concepts of operations. NextGen is being designed to deliver optimal aircraft flight trajectories with better coordinated and managed system-wide operations that will increase capacity and enable aircraft to minimize fuel burn and noise impacts, making it the most efficient aviation system possible.

Since the FAA made a change in interagency coordination from the JPDO to the Interagency Planning Office (IPO), the NextGen IPO has continued to lead the coordination of several key technology focus areas, such as the prioritization of UAS related research and development across federal agencies.

Air traffic controllers currently rely on simple decision support tools to safely separate and maintain an orderly flow of aircraft within the National Airspace System. FAA's traffic forecasts predicted increased traffic, so enhanced tools will maintain and increase system performance. NASA is developing advanced automation tools that will provide controllers with more accurate predictions about air traffic flow, weather, and routing. NASA's Air Traffic Management (ATM) research and development ensures that these tools work well together and demonstrate the potential of widespread use of new procedures throughout the system.

Our successful model for collaboration is embodied in Research Transition Teams (RTTs), which are designed to enhance progress for NextGen advancements in critical areas and effectively transition advanced capabilities to the FAA for certification and implementation. RTTs serve as the bridge between NASA's long term, game-changing technology R&D, and once the capabilities are transferred to FAA, near term R&D to support implementation and certification. Under RTTs, NASA and FAA develop joint research plans and fund their respective portions of the planned research with NASA maturing operational concepts to a certain technology readiness level before transitioning them to the FAA for additional development and eventual implementation. .

This model for cross-agency collaboration and cost sharing has been very effective, resulting in several recent demonstrations of advanced technology benefits. Over the last four years, NASA has transitioned to FAA five technologies for certification and integration into mid-term (2014-2018) NextGen operations.

In July 2011, NASA transferred to the FAA tools and methods for in-flight Flow-Based Trajectory Management (FBTM) in the NextGen. The concept of FBTM demonstrated an effective method for successful management of future aircraft traffic densities at levels 30 percent greater than today without additional controller resources. In September 2011, NASA also transferred assessment tools for proposed airspace redesign for FAA's Cleveland Air Route Traffic Control Center (ARTCC).

In November 2011, NASA transitioned the Efficient Descent Advisor (EDA) technology which will save fuel by enabling more efficient arrivals into congested airports. EDA was developed and field tested through a three-year collaborative effort between NASA, FAA, Boeing, MITRE, Sensis/SAAB, United Airlines and Continental Airlines. NASA estimates $300 million in fuel savings per year during descents if EDA is implemented fleet-wide at the nation's busiest airports. FAA is deploying incremental EDA capabilities as part of its Time Based Flow Management (TBFM) and Enroute Automation Modernization (ERAM) programs with anticipated use by 2018.

NASA transitioned the Precision Departure Release Capability (PDRC) to the FAA in 2013 after a successful field demonstration at the Dallas-Ft. Worth International Airport. PDRC's precision

scheduling of departing aircraft allows for smooth integration into available slots in the high-altitude overhead streams. Missed departure slots in the overhead stream translate to departure delays and lost system capacity. PDRC can result in $20 million in annual system-wide savings. The FAA is currently conducting investment decision analysis on this capability through the Terminal Flight Data Manager (TFDM) and Time Based Flow Management (TBFM) programs.

NASA is partnering with national airspace system stakeholders to demonstrate the ground-based Controller Managed Spacing combined with the Flight Deck Interval Management technologies to enable fuel and time savings along with increased capacity for early adopters of ADS-B equipment. In order to demonstrate user benefits of these concepts, NASA is jointly working with the FAA to partner with airlines, aircraft manufacturers, avionics manufacturers, ground-based automation system integrators, and airports. NASA transferred the ground-based tool portion of this technology known as Terminal Sequencing and Spacing (TSS) suite to the FAA in July 2014 for near-term deployment through its enhanced terminal productivity program. The automation tool is designed to help air traffic controllers manage airspace within the Terminal Radar Approach Control areas (TRACONs) surrounding major airports, safely permitting more flights to merge together at a point where they can be cleared for a final approach and landing.

TSS just received a final investment decision from the FAA as part of its Time Based Flow Management (TBFM) program, which sets the stage for implementation across the National Airspace System. FAA intends to deploy the software tool throughout the NAS, including five major international airports located in Phoenix, Houston, Atlanta, Seattle and Los Angeles, before 2018.

NASA continues its development of algorithms for managing airplane traffic on the ground that will lead to reduced surface congestion enabled by NASA's Spot and Runway Departure Advisor (SARDA) technology. Benefit studies for several complex U.S. airports show a taxi delay reduction of between three to five minutes resulting in annualized fuel savings of $2.5 million to $7.5 million at each airport using these algorithms. A series of simulations leading up to field demonstrations at a major commercial airport are being planned to facilitate the transition of this technology to the FAA in the coming two years.

NASA R&D is helping to enhance NextGen through transfer of technology to industry as well. Some airspace operations tools can be applied directly by airlines in the existing air traffic control system yielding near term benefits.

For example, NASA has developed a tool that combines National Weather Service real-time data with Air Traffic Control departure scheduling to provide enhanced decision support capability to FAA's Ground Delay Program. FAA, along with NASA's support, conducted trials of this new capability at San Francisco International Airport (SFO) and demonstrated a significant reduction in ground delays due to morning fog compared with the current ground delay policy at SFO, which often leads to excessive and unrecoverable delays affecting the entire country. Seventy percent of air traffic delays are caused by bad weather. Until now, airline dispatchers and FAA traffic managers didn't have a way to continuously reevaluate the weather avoidance routes for each flight, which are typically put in place before the aircraft departs. NASA's Dynamic Weather Rerouting (DWR) tool will enable dynamic, "real-time" adjustments to flight paths to avoid bad weather with minimum delay while also saving fuel. The tool integrates trajectory-based automation designed for Center radar controllers, convective weather modeling that predicts the growth and movement of storms, and algorithms to automatically compute minimum-delay routes around bad weather. DWR has the potential to provide significant savings to airlines against those overall operational costs in flight and on the ground. American Airlines participated in DWR technology

demonstrations and has incorporated this tool into daily operations. NASA is working with other industry partners to make this tool more broadly available.

Looking to the near future, we are partnering with the FAA, manufacturers, airlines and airports to conduct near-term demonstrations, planned for 2017, of fuel-saving air traffic management concepts enabled by the satellite navigation capability of NextGen through the ATM Technology Demonstrator-1 or ATD-1 activity. Through simulations and flight trials of a complex, integrated set of ground-based and flight deck technologies, we will demonstrate to airlines the return on investment they can achieve by equipping their aircraft with NextGen avionics such as Automatic Dependent Surveillance – Broadcast (ADS-B) equipment.

Looking further ahead, we plan to demonstrate a full suite of Integrated Arrival/Departure/Surface (IADS) tools which will enable further revolutionary advances in air transportation. This will be done jointly with the FAA in response to the NextGen Advisory Committee recommendations for near term technology demonstrations.

UAS / Autonomy – Multilevel Coordination

NASA also is researching other technologies which hold great promise for the transformation of our future aviation system, including Unmanned Aircraft Systems and more broadly inclusive autonomous systems and technologies. All elements of an aviation system could possess some level of autonomy, ranging from flight vehicles to air traffic management, ground support vehicles, ground control stations and all other elements. The introduction of autonomous vehicles and technologies can usher in totally different flight vehicles and operations that are unimaginable today and open up entirely new commercial markets, benefitting consumers as well as manufacturers, much as jet engines did 60 years ago.

The majority of NASA's research work toward near-term integration of UAS into the National Airspace System is focused on contributing capabilities that reduce technical barriers related to the safety and operational challenges associated with enabling routine UAS access to the NAS. Through close coordination with the FAA's UAS Integration Office, industry standards organizations, and international organizations, NASA's research provides validated findings that inform the FAA's policy and rule-making processes.

NASA also is researching novel concepts and technologies that may facilitate safe operation of UAS at altitudes that are not actively controlled today, such as low-altitude operation of small UAS (less than 55 pounds). Initial investigations in this capability have drawn interest among a broad range of traditional and non-traditional aerospace companies and show promise of opening up entirely new markets and operational models. In order to safely enable widespread civilian UAS operations at lower altitudes, NASA is initiating development of an air traffic management-like system called UAS Traffic Management (UTM). The goal of UTM is to enable safe and efficient low-altitude airspace operations by providing critical services such as airspace design and geo-fencing, separation management, weather and wind avoidance, routing, and contingency management.

The growing UAS industry and the varied user base is a harbinger for change that increasingly autonomous systems will bring to aviation. It has the potential to revolutionize existing transportation applications and enable fundamentally new uses of the NAS. But enabling these changes will require substantial research and experimentation to ensure the safety and efficacy of these systems. As the National Research Council (NRC) Committee on Autonomy Research for Civil Aviation indicated in their recent report on the subject – "civil aviation is on the threshold of potentially revolutionary changes

in aviation capabilities and operations associated with increasingly autonomous systems. These systems, however, pose serious unanswered questions about how to safely integrate these revolutionary technological advances into a well-established, safe, and efficiently functioning NAS."

NASA's long-term research in autonomy seeks to answer both those questions as well as to demonstrate high payoff, integrated applications that advance the safety, efficiency and flexibility of the NAS and increase competitiveness of the U.S. civil aviation industry. Through internal assessments and taking advantage of the previously mentioned NRC Committee's report, NASA has developed a set of research themes that are critical to enabling assured autonomy. These research themes include: advancing test, evaluation, verification and validation techniques; developing autonomous planning, scheduling and decision-making methods; developing the tools to design and analyze autonomous systems; and systems for integrated vehicle control, health management and adaptation.

Future Work

Over the next two years, NASA will continue to develop, demonstrate and transition new vehicle and airspace management concepts and technologies to industry and the FAA as well, to provide technical data, analysis and recommendations to support the integration of UAS into the NAS. We will strengthen our external partnerships through joint flight demonstrations of advanced flight deck and vehicle technologies, and through demonstrations of advanced sensors to improve safety and identify emerging faults before damage occurs.

We are developing roadmaps in key areas such as autonomy and low carbon propulsion, informed through community engagement and studies commissioned through the National Research Council.

Also we are looking beyond traditional aeronautics for technology partners that could transform aviation. We're looking to how technologies that are revolutionizing other industries might do the same if applied to aviation – like smart materials such as shape memory alloys and self healing materials, additive manufacturing (3D printing), and information technology. NASA already works in some of these areas but the leaps-and-bounds advances in other parts of the economy could move us along even faster.

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Conclusion

In summary, NASA does not build aircraft, engines, or air traffic management systems. Through the research we conduct and research we sponsor with universities and industry, we help to develop the technology that enables continuous innovation in aviation. U.S. companies are well positioned to build on discoveries and knowledge resulting from NASA research, turning them into commercial products, benefiting the quality of life for our citizens, providing new high-quality engineering and manufacturing job opportunities, and enabling the U.S. to remain competitive in the global economy.

NASA Aeronautics has experienced tremendous success through the past years by committing to the core principles of:

- valuing innovation and technical excellence;
- aligning our research to ensure a strong relevance to national needs;
- transferring technology in a timely and robust manner;
- maintaining strong partnerships with other government agencies, industry and academia; and
- inspiring the next generation of engineers and researchers.

Our planned research for the upcoming years will continue to provide valuable benefits to the aviation community and the Nation.