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Statement of

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Mr. Chairman and Members of the Committee, thank you for this opportunity to testify on NASA's Aeronautics Research program and the R&D challenges associated with Unmanned Aerial Systems and Autonomy.

Importance of Aviation

NASA's innovative aeronautics research and development portfolio is aimed at transforming the aviation industry through game-changing advances in the safety, capacity, and efficiency of the air transportation system, while minimizing negative impacts on the environment. NASA's FY15 aeronautics research portfolio is aligned with six strategic research thrusts to directly address the growing global demand for mobility, severe challenges to sustainability of energy and the environment, and technology advances in information, communications, and automation technologies.

NASA Aeronautics Research Mission Directorate (ARMD)'s strategic thrust in Assured Autonomy for Aviation Transformation defines ARMD's vision and approach for supporting the integration of Unmanned Aircraft Systems (UAS) into the National Airspace System (NAS) in the near-term while pioneering the more extensive transformative changes that increasingly autonomous aviation systems will bring over the mid to far-term. Research to address this strategic thrust is primarily focused in two Programs – the Integrated Aviation Systems Program, and the Airspace Operations and Safety Program – although there will be implications of autonomy across the entire ARMD portfolio.

Unmanned Aerial Systems and Autonomy

UAS and more broadly inclusive autonomous systems and technologies hold great promise for the transformation of our future aviation system. 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. We are witnessing the dawn of a new era of aviation innovation. 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. Under Section 333 of the FAA Modernization and Reform Act of 2012 the FAA has granted regulatory exemptions for UAS operations for companies performing operations for aerial surveying, construction site monitoring, oil rig flare stack inspections, and film and video productions. NASA and US industry are actively exploring autonomy concepts and technologies specific to the aviation enterprise, as well as identifying advances in other sectors (automotive, electrical systems, or internet-of-things, to name a few) that could be adapted to aviation. The United States is not the only country seeing this opportunity – there is significant interest and research in aviation autonomy by our international counterparts as well, presenting strong competition and at the same time many opportunities for collaboration to advance the state-of-the-art in this field.

There are significant research challenges associated with the introduction of autonomous systems and technologies into our aviation system. Before becoming operational, autonomous systems will need to uphold the highest levels of safety and assurance. This requires the complex systems to be evaluated through new methods and approaches to verify and validate that these systems are operating as designed as well as certifying these systems for flight. New test and evaluation capabilities are required for the development, integration, and evaluation of these autonomous systems.

Introduction of UAS into the NAS is the first stepping-stone on the path toward the introduction of autonomous systems more broadly. Significant barriers exist for routine UAS access such as the lack of an on-board pilot to see and avoid other aircraft, the reliance on command and control communication frequencies used primarily by the military, and the wide variation in UAS size (e.g., Northrop Grumman Global Hawk, which has a 131 foot wingspan and has an empty weight of almost 15,000 pounds vs. AeroVironment Nano Hummingbird, which has a 6.3 inch wingspan and weighs less than an ounce) and performance characteristics (altitudes, speeds, and duration). Understandably, in order to continue to ensure safety of the NAS, the FAA needs to gather information in each of these areas in order to determine the safety of these aircraft, and to set prudent operations and equipment standards before routine access is granted.

NASA's Research and Development Approach

ARMD is not the end user of the concepts and technologies resulting from our research. NASA does not build and sell aircraft, engines, or air traffic management systems. Through the research we conduct and the research we sponsor with universities and industry, we help to develop the technology that enables continuous innovation in aviation.

Close coordination with our partners and stakeholders throughout the research process is essential if we are to successfully transfer new operational concepts and technologies for commercialization by industry, or adoption by the FAA and other federal agencies to help them meet their missions. By matching NASA mid- and far-term research with current problems and making a timely transfer of the needed technology, we are helping the FAA and other stakeholders to realize benefits in near term applications.

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. In addition, JPDO led the way in developing the first set of inter-agency UAS integration goals, a comprehensive plan and an attendant Research, Development and Demonstration Roadmap for UAS integration into the National Airspace System. This work established the foundation for subsequent interagency and industry collaboration that has led to the progress we have seen thus far. 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 including the prioritization of UAS related research and development across federal agencies.

One can characterize NASA's research and development efforts focused on autonomous systems into three time frames, near-, mid- and far-term. The following three sections describe NASA's work in these three time frames and the approach that NASA is taking to coordinate our work with the stakeholder community and transition research findings in an effective manner.

Near-Term - The UAS Integration in the NAS Project

The majority of NASA's research work toward near-term integration of UAS into the NAS is organized under the UAS Integration in the NAS Project, which is part of the Integrated Aviation Systems Program. The goal of the project is to contribute capabilities that reduce technical barriers related to the safety and operational challenges associated with enabling routine UAS access to the NAS.

Current work is focused in these areas that represent key barriers to UAS integration.

Sense and Avoid/Separation Assurance Interoperability (SSI)

Fundamental questions that must be addressed to effectively and safely integrate UAS in to the NAS include, but are not limited to: How can UAS sense other vehicles and avoid them? What are the appropriate variables needed to evaluate the safe interoperability of manned and unmanned aircraft in the NAS? How do you quantify those variables in a way that could lead to aircraft certification minimum operating standards of the sense and avoid system?

This research area focuses on validating technologies and procedures for UAS to remain an appropriate distance from other aircraft and to safely and routinely interoperate with other aircraft in the NAS. NASA research will help determine the combination of technologies, systems, procedures and standards required to ensure that UAS operating in the NAS remain outside the separation minima defined by the FAA. To get to that point, we first need to:

- Determine the performance requirements for a "certifiable" sense-and-avoid system (SAA) that replaces the pilot's eyes and that fulfills the requirement to "see" and avoid other aircraft.
- Determine the impact of these SAA system requirements on the NAS and whether procedures or standards should be modified to minimize the impact.

NASA researchers will employ a suite of methodologies to address this safety goal including simulations and flight tests. Research results will be transitioned to various stakeholders including the FAA and Radio Technical Commission for Aeronautics (RTCA) Special Committee (SC)–228 Minimum Operational Performance Standards for Unmanned Aircraft Systems. RTCA SC-228 will use results to support the development of recommendations for SAA system requirements and performance standards. NASA also anticipates that industry stakeholders will use these results to guide the design and implementation of new SAA systems.

Communications

Communication is another critical element for safe UAS operation. What frequency spectrum is appropriate for UAS? How do we develop and test a communication system? What are the security vulnerabilities that might exist in such a communication system?

The UAS Communication work within NASA's UAS Integration in the NAS Project addresses safety aspects of UAS communications when operating in the NAS.

- The Project is working with the international community to identify spectrum bands to enable safe control of UAS. NASA assisted the community to identify spectrum for line-of-sight (terrestrial) UAS communications and to consider spectrum for beyond line-of-sight (satellite) for UAS communications.

- NASA is testing a prototype control communication radio system to allow the validation of proposed UAS communication system requirements in a relevant environment, utilizing frequency bands identified for UAS operations.

- NASA is working in partnership with the FAA and National Institute for Standards and Technology (NIST) to analyze and develop mitigations to potential security vulnerabilities of the UAS control communication system.

- NASA is conducting large-scale simulations of the UAS communication systems that would be needed for a NAS-wide deployment of UAS.

Human Systems Integration (HSI)

Given effective communications, humans will continue to play a role in highly-automated UAS operations. How does the NAS accommodate a UAS pilot who is on the ground compared to a pilot in the cockpit? How do we design ground control station displays to maximize pilot effectiveness and safety?

NASA researchers in this focus area are working to ensure that the unmanned aircraft pilot operates as safely in the NAS as a manned aircraft pilot. Human Systems Integration (HSI) is achieving this through: 1) identifying the tasks and requirements that allow a pilot to operate safely; 2) developing a prototype ground control station (GCS) that supports those tasks and requirements; and 3) demonstrating this capability in simulation and flight tests in both nominal and off-nominal conditions. The results of this work will be the basis for developing guidelines for GCS designed to operate in the NAS.

- The HSI element is performing a systematic evaluation of the task and information requirements ultimately including consideration of FAA Federal Aviation Regulations (FARs) for design and safe operation in the NAS.

- A prototype GCS is being developed and evaluated to present the required information to the pilot and support the tasks required.

The lessons learned from these Human Systems Integration evaluations will inform GCS design guidelines for operations in the NAS that will be vetted through RTCA SC – 228 leading to recommendations to the FAA.

Technology Transfer

The driving force behind NASA's UAS research is to be able to transfer tools and solutions for operation in the civil airspace to the UAS community. Transfer is enabled by the coordination and close working partnerships that form during the research process. Through our earlier involvement with the NextGen JPDO, NASA learned much about how to work efficiently and effectively across various federal agencies and with multiple industry partners and interests. We have applied those experiences and lessons to how we prioritize, execute and transfer our research findings to the stakeholder community.

Inter-Government Interfaces

The work that NASA is performing to support the safe integration of UAS into the NAS is dependent on external government agency interfaces to coordinate ongoing work as well as to transfer research deliverables. To ensure that the research products NASA delivers are well aligned across the multi-agency, multi-national efforts to enable routine UAS access to national and global airspace, NASA's R&D efforts require close coordination with the FAA's UAS Integration Office, industry standards organizations, and international organizations. The close working relationship with the FAA's UAS Integration Office is critically important to ensure that NASA's research provides validated findings that inform the FAA's policy and rule making processes. This includes the prioritization of key technologies to research, as well as the design of critical simulations and flight test campaigns.

Other formal and informal interfaces and forums are also vitally important for collaboration and coordination of inter-Agency research. Two key inter-government interfaces that NASA is involved in are the UAS Executive Committee (ExCom) and the Sense and Avoid Science and Research Panel (SAA SARP).

In response to integration challenges and the growing demand for UAS NAS access by government agencies, Congress created the UAS ExCom. The UAS ExCom was created in order to enable the DoD, the DHS, and NASA to obtain routine UAS access to the NAS in order to execute their agency missions of national defense, security, and scientific research. The expectation is that the experience gained by these agencies may enable the FAA to extend normalized or routine operational procedures to other public UAS operators and eventually civil UAS operators. The composition of the UAS ExCom includes senior executives from all four agencies. NASA also supports the work of the UAS ExCom through participation on its Senior Steering Committee and associated Working Groups. Working closely with the ExCom, the FAA has streamlined the Certificate of Authorization (COA) application process and extended the length of the COA from 12 months to 24 months. In addition, the FAA has established expedited procedures to grant one-time COAs for time-sensitive emergency missions such as disaster relief and humanitarian efforts.

NASA supports and closely cooperates with the DoD chartered Sense and Avoid Science and Research Panel (SARP). The Office of the Secretary of Defense recognized that a key challenge to integrating UAS into the NAS is a means for UAS to sense and avoid other aircraft. To ensure sound technical approaches to overcome this challenge OSD has established a SARP composed of experts from organizations that are performing SAA research. The SARP's primary purpose is to promote partnerships between the DoD and the broader academic and science community on UAS NAS integration science and research initiatives. The stakeholder community benefits from these partnerships through a broader range and depth of scientific expertise applied to challenges that affect all aspects of potential UAS operations. Since inception, NASA has played key roles supporting the SAA SARP with subject matter experts and executive leadership.

NASA is collaborating with the DoD in several other key areas as well. NASA is working closely with the Air Force Research Lab to leverage research efforts associated with sense and avoid, particularly related to the Jointly Optimal Collision Avoidance research and on human factors efforts related to UAS access. The Project is working with US Northern Command in their flight test efforts to validate the DoD Concept of Operations for UAS access. NASA is working with the Navy Broad Area Maritime Surveillance Program on safety case analysis in addition to sense and avoid testing. This will again provide specific additional data related to routine access for both public and civil aircraft. NASA is also coordinating research activities with the DoD Policy Board for Federal Aviation and the Office of the Secretary of Defense's UAS Task Force to further expand our collaborations with the DoD.

Industry Interfaces

In addition, NASA works closely with industry and other government agencies on the UAS Aviation Rulemaking Committee and RTCA Special Committee 228, which was described earlier. NASA is an integral contributor to the FAA's UAS Aviation Rulemaking Committee. This committee was formed to provide a forum for the Nation's aviation community to discuss UAS related issues, and provide recommendations to the FAA for various UAS rulemaking projects. This includes providing information and input to the FAA to help develop the means to continue integration of UAS with manned NAS operations that address safety, capacity, and efficiency objectives consistent with global aviation. NASA is involved at the executive level as a member of the UAS Aviation Rulemaking Committee and provides subject matter experts to support various working groups.

Global Harmonization

A final area of collaboration in which NASA is engaged is global harmonization. The data and research findings that are being developed in the Communications activity are being shared with the international community through the International Telecommunication Union meetings associated with the World Radio Conference. NASA is also involved in several International Civil Aviation Organization (ICAO) activities as part of the U.S. delegation led by the FAA and the State Department, including the Flight in Non- Segregated Airspace work, the UAS Study Group, the Civil Air Navigation Services Organization, and various ICAO working groups.

Mid-Term – UAS Traffic Management/UTM concept

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 trade space 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.

Many beneficial civilian applications of UAS have been proposed for operation in this airspace, from goods delivery, agricultural monitoring, and infrastructure surveillance, to civil emergency search and rescue. As some UAS operations may operate in the same airspace where a mix of general aviation aircraft, helicopters and gliders currently operate, there is a strong need to safely accommodate all of these vehicles at lower altitudes. Currently, there is no established infrastructure to enable and safely manage the widespread use of low-altitude airspace and UAS operations, regardless of the type of UAS.

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), much like today's surface vehicles that operate within a system consisting of roads, lanes, stop signs, rules, and lights. 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. UTM will support UAS ranging from those with minimal avionics capability, to those that are autonomous, and allow safe operations in presence of current vehicles (e.g., gliders, general aviation, helicopters). UTM is essential to enable the accelerated development and use of civilian UAS applications. UTM will provide structure such as corridors and geo-fences where absolutely necessary and flexibility where possible.

Two types of UTM systems are envisioned. The first type is a Portable UTM System, which would move between geographical areas and support operations such as precision agriculture and disaster relief. The second type of system is a Persistent UTM System, which would support low-altitude operations and provide continuous coverage for a fixed geographical area. The UTM will require persistent communication, navigation, and surveillance coverage to track, ensure and monitor conformance. Industry is considering a variety of options such as ground-based radars, cell phone, and satellite based Automatic Dependent Surveillance - Broadcast ADS-B for surveillance and tracking.

NASA's near-term goal is the development and demonstration of the UTM to safely enable low-altitude airspace and UAS operations within five years. For the longer-term (10 to 15 years in the future), the goal is to safely enable the anticipated dramatic increase in density and diversity of all low-altitude airspace operations. Working alongside with many committed government, industry and academic partners, NASA will lead the research, development, testing, and implementation of the UTM, exploring functional designs, concepts and technology development, and testing of proposed UTM systems utilizing a series of builds, each increasing in capability. NASA is using a spiral development approach targeting these four builds to be delivered at 12-16 months intervals.

During the UTM's development, NASA has collaborated closely with the FAA. The UTM system concept was presented in an all-stakeholder workshop in February 2014 that was attended by over 150 representatives from UAS manufacturers, operators, system integrators, test sites, as well as the FAA, NOAA, and DoD.

From the stakeholder workshop attendees there was solid support for the concept and NASA's role as a coordinator. Further, many organizations expressed interest in building partnerships with NASA to develop and test UTM. As a result, several Space Act Agreements have been developed. In order to ensure further inclusiveness, NASA issued a request for information on the federal business opportunities website to solicit further collaborators. To date, NASA has received over 100 potential collaboration requests. These collaborators represent UAS manufacturers, operators, software systems developers, communications companies, ADS-B manufactures, and airspace operations providers, to name a few.

NASA has also developed a research transition team (RTT) for UTM with the FAA. This collaboration and technical exchange management structure has successful roots in the delivery of several key air traffic management advanced technologies from NASA to the FAA over the last several years. The RTTs routinely engage FAA's NextGen, Aviation Safety, and Air Traffic Operations organizations, and the William J. Hughes Technical Center.

Interest from the UAS community has been very high, and anticipation of rapid progress in system development and implementation is equally high. The pace of collaborative research and demonstration planned for UTM is critical to address the demand of the UAS community.

After thorough testing, transfer of the technologies associated with a UTM prototype to the FAA is expected by 2019. The ultimate goal of this research is to assist all low-altitude operations (e.g., manned and unmanned) in an autonomous manner to accommodate future vehicles.

Far-Term –A Vision for Adopting Autonomy

The growing UAS industry and the varied user base is a harbinger of the potential 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 National Airspace System. 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 both answer 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.

While the ultimate outcomes of our autonomy research are long-term, the research is beginning today in synergy with other UAS research. For example, the Live, Virtual, Constructive – Distributed Environment being established for high fidelity flight testing and standards validation for the UAS in the NAS Project is being extended to the full NAS to enable shadow mode simulation and testing of advanced airspace architectures including research to achieve real-time, system-wide safety as well as autonomous system operations.

Another example is the later versions of the UAS Traffic Management test-bed that will test the ability to autonomously schedule safe, conflict free trajectories in very complex conditions with vehicles of varying performance. Both of these examples provide platforms for testing advanced verification and validation methods that will be required for confident application of increasingly autonomous systems.

Again, while the ultimate objectives of this research are long term, we also expect that initial applications of increasingly autonomous systems will be viable in the mid-term. Initial focus will be on autonomous functions that collaborate with humans to improve safety outcomes and UAS traffic management.

Conclusions

NASA's Aeronautics Research Mission Directorate is a national resource that, through game-changing research advances, enables a growing, sustainable and transformative aviation system. Increasingly autonomous aviation systems will both help solve evolving safety, efficiency, and sustainability challenges, and enable the type of transformative changes that UAS integration signals. For the near-term, NASA is playing an important role, in partnership with the FAA, DoD, standards developing organizations, and industry in general, to achieve the integration of UAS into the National Airspace System. This partnership is built upon clear roles and responsibilities among the partners, long and productive working relationships, and close and continuous coordination for the specific needs of the UAS integration challenge.

Moreover, because enabling the introduction of increasing autonomous systems is a major element of NASA's long-term aeronautics strategy, we are committed to sustaining this important partnership. As the challenges of UAS operations evolve and the broader implications of the integration of autonomy throughout the aviation system develop, NASA will continue to advance the research and enabling technologies that will assure the safe realization of the transformative benefits of these systems.