Statement of

Edgar G. Waggoner, D.Sc.
Director, Integrated Systems Research Program
Aeronautics Research Mission Directorate
National Aeronautics and Space Administration

before the

Subcommittee on Oversight
Committee on Science, Space and Technology
U.S. House of Representatives

Mr. Chairman and Members of the Subcommittee, thank you for this opportunity to testify on NASA's Research and Development (R&D) efforts to enable safety in the operation of Unmanned Aircraft Systems (UAS) in the National Airspace System (NAS).

Introduction

There is a growing demand to routinely fly UAS in the NAS. Unmanned Aircraft Systems are increasingly being used for applications where it is not feasible or practical to rely on extended human-piloted flights. Examples include long-duration scientific research, remote sensing, firefighting, land and crop monitoring and surveying, border protection, emergency management, and airborne communications. The application of unmanned aircraft to perform these national security, defense, scientific, and emergency management tasks is driving the critical need for broader integration of UAS into the National Airspace System.

Routine access of UAS to the NAS represents the promise of new capabilities for the government (public) and commercial (civil) aviation sectors. However, the Federal Aviation Administration (FAA) will not integrate UAS unless and until we can be assured the safety of the NAS will not be degraded. The growth

of this potential industry has not yet been realized because additional research must be done to determine what is required to safely operate UAS in the NAS. NASA is performing research in the Aeronautics Research Mission Directorate (ARMD) that provides an opportunity to transition concepts, technologies, algorithms, and knowledge to FAA and other stakeholders to help them define the requirements, regulations, and issues for routine UAS NAS access.

To be clear on the role that NASA Aeronautics plays in this effort—NASA does not build unmanned aircraft for the civil market nor develop the regulatory framework for their operation in the NAS. Rather, through the research we conduct, we address critical technology challenges for UAS integration in these key areas:

- Sense and Avoid/Separation Assurance Interoperability
- Communication
- Human Systems Integration
- Support of UAS Certification Requirements

Our research efforts and resulting deliverables are effectively coordinated with, and planned for seamless transition to, the UAS stakeholder community.

Barriers to Integration

Why aren't Unmanned Aircraft Systems allowed routine access to the NAS now?

Existing Federal Aviation Regulations (FAR) procedures and technologies do not allow routine UAS access to the NAS. Access to the NAS is hampered by challenges such as the lack of an on-board pilot to see and avoid other aircraft, the reliance on command and control (C2) communication frequencies used primarily by the military, and the wide variation in UAS size (e.g. Northrop Grumman Global Hawk vs. AeroVironment Nano Hummingbird) and performance characteristics (altitudes, speeds, and duration at which UAS operate). Understandably, 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, in order to continue to ensure safety of the NAS.

The FAA has established a process enabling public agencies to request a Certificate of Authorization or Waiver (COA) to operate UAS in the NAS. Recently, the FAA has worked with government partners to streamline the COA application process and extended the length of the Authorization from 12 months to

24 months. In addition, the FAA has established expedited procedures to grant one-time Certificate of Authorization or Waivers for time-sensitive emergency missions such as disaster relief and humanitarian efforts.

For civil (non-public) UAS operations in the NAS, the FAA requires a special airworthiness certificate in the experimental category. Because of safety concerns, experimental Certificates (ECs) are limited to an individual vehicle, rather than to a class of vehicles.   For example, commercial operations are specifically excluded under an EC.

The UAS Integration in the NAS Project

The majority of NASA's research work toward integration of UAS into the NAS is organized under the UAS Integration in the NAS Project, which is part of the Integrated Systems Research 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.

Research Area: Sense and Avoid/Separation Assurance Interoperability (SSI)

How can UAS sense other vehicles and avoid them? What are the appropriate variables necessary 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 that fulfills the requirement to "see" and avoid other aircraft.* The existing requirement is intentionally vague to allow for pilot discretion in determining the "appropriate

distance" to remain from other aircraft but for UAS to contain a "certifiable" SAA system the requirements for remaining an "appropriate distance" cannot be vague and must be quantified. Otherwise it will be difficult to measure whether a given Target Level of Safety (TLOS) is achievable.

- *Determine the impact of these SAA system requirements on the NAS and whether procedures or standards should be modified to minimize the impact.* An SAA system that meets the TLOS will likely give the UAS pilot greater awareness about nearby traffic than has a manned pilot using only his or her eyes. This greater awareness may make a UAS pilot operate in different ways that impact the NAS differently than manned aircraft. For example, UAS pilots may contact Air Traffic Control more frequently to request maneuvers to avoid distant traffic, increasing controller workload. UAS in the NAS Project researchers will study the new impacts that a SAA-equipped UAS will have on the NAS and explore strategies (procedures, standards, technologies) to minimize those impacts.

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) – 203 Unmanned Aircraft Systems. RTCA SC-203 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.

Research Area: Communications

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 a communication system?

The UAS Communication work with 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 the consider spectrum for beyond line-of-sight (satellite) for UAS communications at the 2012 World Radio Conference. NASA is currently conducting analyses to

assist in identifying additional beyond-line-of-sight frequency bands for UAS communications at the 2015 World Radiocommunication Conference.

.

- NASA is developing 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. This effort is in partnership with an established aircraft avionics manufacturer, Rockwell Collins, who has developed and fielded numerous radio systems certified by the FAA. NASA is conducting flight validation of a prototype UAS communication system as a full end-to-end system test, incorporating systems and algorithms from other UAS in the NAS sub-projects. The testing of this system in a realistic flight environment enables the proposed communication system requirements to be rigorously evaluated, in order to establish a basis for the minimum performance standards necessary for a FAA-certified UAS control communication system.

- 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. The security analysis follows applicable NIST security standards, guidelines and processes. The developed security mitigations are being validated through flight tests of a full end-to end system.

- NASA is conducting large-scale simulations of the UAS communication systems considering a NAS-wide deployment of UAS. These simulations are being utilized to validate the ability to scale the prototype communication system to future anticipated UAS traffic levels, as well as exploring the effect the UAS communication system may have on manned aircraft traffic.

NASA and the FAA are working in partnership to analyze and develop mitigations to potential security vulnerabilities of the UAS control communication system.

Research Area: Human Systems Integration (HSI)

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 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 test and 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. Three information requirements analyses have been conducted to fulfill this objective: 1) analysis of the phase of flight of the aircraft; ground operations, departure, cruise and approach and landing; 2) a functional analysis, i.e., aviate, navigate and communicate; and 3) a requirements study carried out in conjunction with the FAA focused on evaluating applicability of current FARs to UAS.

When the requirements are well understood, a prototype Ground Control Station (GSC) will be developed to present the required information and support the tasks required. A survey of over 100 existing Ground Control Stations has been conducted to ensure the industry lessons learned and state of the art for GCS design are well documented. Further, a similar analysis of applicable manned aircraft technologies is underway to make use of the decades of superior aeronautical engineering. Human factors best practices will be employed in the development of the prototype GCS.

The lessons learned from these Human Systems Integration evaluations will inform GCS design guidelines for operations in the NAS that will be vetted through Radio Technical Commission for Aeronautics (RTCA) Special Committee (SC) – 203 leading to recommendations to the FAA.

Research Area: Support of UAS Certification Requirements

What data needs to be collected on the road to developing guidelines for UAS aircraft certification? What criteria are critical for avionics, communication and GCS certification?

To help identify what role certification can play in safe integration of UAS in the NAS, NASA Aeronautics is: (1) collecting and analyzing data on safety-related hazards from UAS operations, and (2) analyzing risk factors that underlie development of system safety standards for UAS.

Work is underway to collect incident, accident, and system failure data to increase our understanding of UAS failure modes and hazards experienced to date. The majority of data on UAS incidents and accidents comes from military and public-use operations, where the quality and availability of data records are extremely variable, making comprehensive analysis difficult. NASA Aeronautics is currently acquiring data across many of NASA's science missions that employ UAS and data that has been made publicly available from the FAA's COA process. Various modeling and data mining techniques are being applied to analyze that data and to advance data collection and analyses methods, with the goal of facilitating proactive identification of UAS safety issues.

Work is also underway to analyze how risks inherent in the design and operation of UAS affect the specification of airworthiness standards; that is, aircraft and system-specific design and performance standards that promote safe flight. To attain routine access to the NAS, minimum standards must be established or adapted from current standards for manned aircraft that provide confidence in system reliability and safe operation.

NASA's UAS Integration in the NAS Project is examining the degree to which existing design standards and reliability requirements may serve as an appropriate certification basis for UAS, and sharing the results of this examination with FAA. That degree depends, at least in part, on whether aviation hazards or other risk factors significantly change based on operational or physical attributes of the UAS, such as the separation of the cockpit and pilot of the aircraft from the vehicle itself. Even in the most conventional UAS designs, significant new hazards may arise from ground control stations, communication links, and specialized avionics. The effect of failures in these elements, separately or in combination, can bring a new twist to long-established hazards such as loss of aircraft control and loss of situational awareness. Evaluation of various risk factors, coupled with lessons learned from incidents and accidents, is intended to support development of a well-founded safety case for integrating UAS into the NAS.

Technology Transfer

As stated earlier, the driving force behind NASA's UAS research is to be able to transfer tools and solutions for operation in civil airspace to the UAS community. Transfer is enabled by the coordination and close working partnerships that form during the research process.

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 this end, three key inter-government interfaces that NASA is involved in are the UAS Executive Committee (ExCom), the Joint Planning and Development Office (JPDO), and the UAS Aviation Rulemaking Committee (ARC).

In response to integration challenges and the growing demand for UAS NAS access by government agencies, Congress created the UAS Executive Committee (UAS ExCom). The ExCom was created in order to enable DOD, 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 final composition of the 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.

NASA supports and closely cooperates with the Joint Planning and Development Office in cross-agency efforts to coordinate integration activities and document governing consensus to support UAS integration. The NASA Administrator is a member of the Senior Policy Committee and the Associate and Deputy Associate Administrator for the Aeronautics Research Mission Directorate are active JPDO Board members. NASA also supports UAS integration efforts at JPDO through active participation in various working level efforts that focus on specific integration challenges. NASA is supporting the JPDO on developing the UAS Comprehensive Plan, a national roadmap for civil UAS access (in conjunction with the FAA's UAS ARC), identifying specific NASA contributions to a Research Development and Demonstration Roadmap, and developing national goals and objective for UAS integration.

NASA also works as an integral contributor to the FAA's UAS Aviation Rulemaking Committee (ARC). 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.

In addition to the formal interfaces described, the work NASA is performing requires close coordination with the FAA's UAS Integration Office, industry standards, organizations, and international organizations in an effort 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.

Partnerships and Agreements

The UAS community is both broad and deep. NASA and DoD have extensive experience in flying UAS in segregated and non-segregated airspace over the past 40+ years. Other government agencies, such as DHS, have been flying UAS during the past decade. In addition to operating UAS, many governmental and industry entities have been conducting research in areas of sense and avoid, communications, pilot/aircraft/controller interactions, and other areas related to UAS access to the NAS.

Since there are a multitude of operational and research experiences across the UAS community, it is imperative that NASA fosters partnerships and collaborations in order to ensure that the research products that NASA delivers are both relevant and not unnecessarily duplicative.

Even before the onset of establishing the UAS Integration in the NAS Project, NASA began to build partnerships with the two key customers, the FAA and RTCA SC-203, for critical deliverables. With the FAA, NASA is leveraging formal agreements from the past, and has established a new UAS specific agreement to ensure full collaboration at both the management and technical levels. Key personnel from NASA and the FAA have met and will continue to meet routinely to ensure that our deliverables will reduce or eliminate technical barriers for routine civil UAS access to the NAS. With RTCA's SC-203, NASA is represented on all of the Work Groups. NASA is developing research products that will validate the SC-203 standards recommendations to the FAA.

In addition to the partnerships with the FAA and SC-203, NASA is collaborating with the DoD in several key areas. NASA is working closely with the Air Force Research Lab (AFRL) to leverage research efforts associated with sense and avoid, particularly related to the Jointly Optimal Collision Avoidance (JOCA) 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 (BAMS) 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. Based on a request from the UAS ExCom, NASA is validating specific flight test data for Class D airspace. 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 expand our collaborations with the DoD further.

Our involvement with industry has primarily been through NASA Research Announcements (NRAs) or contracts. NASA does have a specific cost sharing arrangement with Rockwell Collins on the development of a prototype UAS communications system.

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 activities as part of the U.S. delegation led by FAA and the State Department, including the Flight In Non-Segregated Airspace work, the UAS Study Group, the Civil Air Navigation Services Organization, and Working Group.

The Reality of Research Gaps

NASA has diligently worked to identify and address the most critical challenges associated with the routine operation and integration of UAS into the NAS. However, two future areas of research have been identified where NASA is undertaking studies to evaluate the implications of safe integration of UAS into the Next Generation Air Transportation System.

Level of Autonomy
As mission complexity and environmental complexity increase, automation technologies can augment piloted control of UAS in much the same manner as in manned aircraft. However, understanding the tradeoffs between remote control and computerized automation of unmanned aircraft systems is relatively immature. As civil UAS interoperate with manned aircraft in the NAS, levels of acceptable automation may well remain a critical obstacle for routine UAS integration and dictate the pace of expansion of the UAS commercial market.

Airborne Based Sense and Avoid (ABSAA)
As previously described, one of the critical challenges for routine UAS access to the NAS is the risk associated with the lack of having an onboard pilot to "see and avoid" other aircraft. This is particularly relevant when one or both aircraft are not under positive control from air traffic controllers. Current

mitigation strategies require a ground based observer or an observer in a chase aircraft maintaining visual contact with the UAS. Significant research has been performed supporting DoD operations that should be assessed for civil UAS applications. This includes addressing research issues of self-separation, collision avoidance, and aircraft detection.

Conclusion

In summary, NASA does not build unmanned aircraft for the civil market nor develop the regulatory framework for their operation in the NAS. However, through the research we conduct in cooperation with other government entities, industry and universities, we are addressing barrier technology challenges for UAS integration into the NAS. This includes critical research being performed in the areas of:

- Sense and Avoid/Separation Assurance Interoperability
- Communication
- Human Systems Integration
- Support of UAS Certification Requirements

NASA is working diligently on various fronts to insure that the research we are delivering is effectively coordinated with and transitioned to the UAS stakeholder community.

The research being conducted by NASA Aeronautics in support of integration of UAS into the NAS supports NASA Aeronautics' 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.