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Chairman Smith, Ranking Member Johnson, and members of the committee: thank you for this opportunity to testify on NASA's Aeronautics Research program and the research and development challenges related to Urban Air Mobility, or UAM.

NASA's Aeronautics research is making air travel safer, more efficient, and more environmentally friendly. NASA conducts transformative aeronautics research for long-term global leadership, engages in collaborative partnerships to achieve high impact near- to mid-term results, and infuses revolutionary technology advancements from non-aerospace fields to benefit the aviation community.

The fledgling UAM market presents a unique opportunity for NASA to play a vital leadership role in 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) is exploring the most critical technical challenges facing this market, from safety, vehicle technologies, to operations, to identify where we can play the greatest role in supporting this new industry.

Exciting Market

This is a very exciting time – we could be looking at a dawn of a new era in aviation, as momentous as the introduction of the jet engine.

Since before the turn of the 21st century, futurists and technologists have been dreaming about flying cars or “personal air vehicles.” Magazines like Popular Mechanics had regular features about people driving out of their garage, down the street and then flying off to work. And there has also been serious study of the use of aviation for intraurban transportation for many decades as planners recognized that greater speed and transport efficiency was possible through the use of aviation technologies for short range application – but the technologies were not available to meet the safety and economic requirements.

NASA's vision for Urban Air Mobility builds on these dreams and transforms them with the promise of a whole new type of mobility - a safe, affordable and efficient system for passenger and cargo air transportation within an urban area (operating over populated areas). UAM vehicles can range from small delivery drones to passenger-carrying air vehicles that have electrically-powered Vertical Take Off and Landing (eVTOL) capability. UAM has the potential to revolutionize how people and cargo move in crowded city (urban) environments.

This new market won't emerge overnight. UAM will likely start with a mix of onboard piloted and remotely-piloted vehicles and slowly progress toward autonomous operations. Although much discussion occurs about

urban air mobility, these operations could also benefit rural and suburban communities by providing faster access to services such as medical or delivery services.

Why could the UAM market be real?

So what is different now?

The digital revolution is enabling a convergence of technology making UAM truly possible for the first time. The ability to gather, share and process massive data sets could support management, control, and operational oversight of fleets of UAM vehicles. Electric power and propulsion systems could make UAM vehicles quieter, sustainable and more affordable to operate. Technologies for safe operation of unmanned systems such as data driven prognostic system wide safety, detect and avoid and vehicle communications are maturing rapidly, getting smaller, more reliable and more capable. Advances in vehicle and operational system autonomy in the air, ground and sea are moving ahead every day. NASA's work on UAS Traffic Management (UTM) has shown the promise of using cooperative data exchange-based operations that will scale to future needs, enabling us to envision a robust UAM system which does not overwhelm the air traffic management system or compromise safety. New technologies such as composite materials and structures and 3D printing could enable automobile-like production rates for UAM vehicles, but which meet the strict safety standards demanded of aviation.

Another change is consumer expectations. Across our society we are finding ways to bring technology to end users on demand and at our fingertips. Now, technology is advancing to the level where we can have the same "on demand" experience in aviation.

We also are thinking about mobility in a new way. Commercial aviation has opened up the world, where affordable travel is possible to almost every corner of the globe. In recent years, new business models for local mobility such as ride sharing have been demonstrated on a massive scale, showing a path for a viable "local mobility service" business model for consumers, manufacturers and service providers.

These trends are combining in a way to enable an entirely new aviation mobility market and opportunity space. We are on the verge of using the entire airspace as a continuum for mobility (ground to very high altitude reaching above 60,000 ft), with safe co-existence of manned and unmanned, small and large air vehicles with various levels of capabilities.

NASA is not the only organization to see the promise of UAM. Traditional aerospace companies, start-ups, and even non-traditional aerospace companies around the globe are investing hundreds of millions of dollars in UAM technologies, all striving to be market leaders. Companies have unveiled experimental vehicles in development. Aspiring service providers like Uber have announced plans to start air ride sharing flights in the 2020s. Some of the largest companies in the world are rolling out plans to deliver packages to our doorsteps using delivery drones. State and local governments are vying to be testing grounds for these new technologies, hoping to bring technology investments, economic growth and jobs to their constituents.

What is NASA's role (general)?

To understand NASA's role in enabling Urban Air Mobility, it may be helpful to first understand the Agency's role in advancing civil aviation to its present state. 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. Examples include the following:

- Low-emissions combustor technologies developed by NASA provided the foundation for today's low-emissions aircraft engine combustors.

- NASA’s composite research in the 1980s and 1990s, focused on reducing weight, reducing manufacturing costs, and increasing the durability of composite materials and structures, which provided a foundation of knowledge that enabled commercialization and widespread use of this technology.
- Research on engine noise developed the understanding that guided the design of chevrons, which are the serrated trailing edges of the engine cowlings that initially were put into service on some regional jets in 2002, and now are highly visible on the Boeing’s 787 and 747-8 aircraft. These chevrons reduce the noise levels within and outside the aircraft by one third.
- NASA studies led to the development of “winglets” - vertical extensions that can be attached to wing tips in order to reduce aerodynamic drag without having to increase wing span, increasing an aircraft’s range and decreasing fuel consumption.
- NASA created and tested the concept of an advanced cockpit configuration that replaced dial and gauge instruments with flat panel digital displays. The digital displays presented information more efficiently and provided the flight crew with a more integrated, easily understood picture of the vehicle situation. “Glass cockpits” now are commonplace on commercial, military and general aviation aircraft.

These and other NASA contributions increased the capacity and improved the efficiency, safety, and environmental compatibility of the air transportation system.

The critical challenge—and opportunity—facing the United States is to remain at the forefront of a growing and evolving aviation market. We must maintain leadership through technological superiority, and NASA Aeronautics has a unique and important role in that formula. NASA Aeronautics will continue its role of setting the long term vision for aviation and undertaking research and development that falls outside the scale, risk, and payback criteria that govern commercial investments. Once NASA explores and demonstrates the feasibility of these high risk, high payoff technologies, U.S. industry can then further mature them and transition them to commercial products. Companies use our ground and flight test infrastructure to validate their concepts and technologies, or to collaboratively explore new innovations for flight. Similarly, NASA’s research provides validated findings that inform the Federal Aviation Administration’s (FAA) policy and rulemaking processes, industry standards, and global aviation standard and recommended practices. NASA research into new air traffic management concepts and technologies directly transitions into FAA upgrades to the nation’s air traffic management system. Together our combined efforts are helping to meet the present and future challenges of a globally connected air transportation system

The challenges

UAM presents a whole range of economic, technical, regulatory and policy challenges. In many ways, UAM represents a total aviation system design challenge. UAM will leverage many of the current regulatory and operational constructs that exist today but will have to develop a set of unique and integrated approaches to satisfying those requirements. In some cases, new rules and operational models will be required. Three of the most significant challenges where NASA might play a role include safety certification, airspace integration, and noise standards and procedures.

Prevailing UAM vehicle concepts employ vertical take-off and landing designs (VTOL) that utilize distributed electric propulsion systems. and have highly automated guidance and control systems. Assuring the safety of these vehicles for operation in densely populated urban areas will be a major challenge. Validated, industry consensus standards will be required in many system areas to serve as a certification basis by the FAA. Once such example could be the standards and means of demonstrating compliance for safely diverting and landing at an alternative site in the event of an inflight emergency.

For airspace operations, much of the time UAM systems will operate in what is today low altitude, uncontrolled airspace. The solution to controlling this airspace cannot be adding more air traffic controllers – they would be unable to manage the dense, high frequency operations that are envisioned. Instead, a distributed, highly automated, service-provider based system with robust data sharing will be needed to seamlessly and safely schedule and deconflict traffic.

Noise will be a primary community acceptance issue. Communities will not accept noise that significantly exceeds background noise levels. Therefore, understanding community response to different noise signatures will be required to craft acceptable aircraft noise standards. It is very likely the case that both aircraft noise reduction technology and operational mitigation procedures will be needed to achieve acceptable noise levels.

These three examples start to demonstrate the level of complexity and integration that exist around the challenges of UAM. It is a systems problem that cannot be solved in a piecemeal fashion or by any one entity. It is only through a collaborative government – industry partnership taking an evolutionary, but comprehensive approach that we will realize the full UAM vision and its economic and transportation benefits.

What is NASA's role (in UAM)?

NASA is uniquely positioned to support the fledgling UAM industry, based on our overall role and expertise in aviation research. NASA is excited to be leading the community in identifying the key challenges facing the UAM market and exploring necessary research, development and testing requirements to address those challenges. NASA is developing a comprehensive, holistic strategy to guide our approach to research and partnership. Major elements of this strategy include:

- market and technology research studies to scope the challenges and solution space;
- development of UTM-inspired airspace management automation and integration;
- a national partnership to develop and validate necessary industry consensus standards and means of compliance for safety;
- technology development leadership in key areas requiring substantial long-term advancement, such as noise reduction and more electric propulsion systems and architectures;
- an early grand challenge to enable the entire community to gauge their individual readiness and the overall system state-of-the-art; and finally,
- a culminating set of flight campaigns that demonstrate the integrated UAM capabilities.

NASA actions/priorities

NASA's current investments focused specifically on UAM are small. However, we are leveraging our existing work and focusing on aligning our capabilities to conduct new research that supports the opening of this new UAM market. NASA investment in UAM is planned to grow as several related research activities conclude in FY2020 and that money is reinvested in new UAM-focused research, and as we leverage our existing portfolio and capabilities to address UAM challenges. NASA's subject matter experts from across the four NASA aeronautics research centers currently are conducting an assessment of the best opportunities to make this transition. Based on our preliminary assessments, we have identified a few key opportunities for NASA leadership and research.

Market assessment

NASA has been assessing the viability of this potential market through market studies and scientific assessment. We have been studying on-demand mobility for some time. Initial studies and focus groups over the last several years to understand the supply side have helped to identify a first set of required technologies and key challenges.

More recently, NASA has initiated studies to understand market barriers and assess future UAM demand. These studies indicate the possibility of commercially viable package delivery and airborne ride sharing or air taxi markets within 10 years, assuming the remaining technological and policy barriers are overcome.

Tools/facilities

NASA research will stimulate innovation in UAM technology and operational concepts by providing access to NASA tools, expertise and facilities. Existing NASA-developed computational vehicle design tools and noise prediction and acoustic modeling software can be leveraged by U.S. industry as they develop new products and services. Using NASA research ground test facilities and flight ranges, companies can test and mature their concepts in simulated and real world flight environments.

Research – Air Traffic Management (ATM)

NASA has been developing ATM concepts and technologies for decades. NASA research will assess the feasibility of UAM operations, and identify requirements to ensure the system operates with the highest safety standards, acceptable levels of noise, with airspace access to new entrants that doesn't burden the current National air traffic control system.

NASA anticipates that UAM flight operations will be enabled through a service-based air traffic management architecture, similar to NASA's UAS Traffic Management (UTM) concept of operations. NASA's UTM capability levels serve as a basis for cooperative airspace operations using standardized data exchange protocols for intent sharing among users. NASA is researching how the UTM concept could apply to UAM missions.

NASA also is researching potential future requirements and applications of a service-based ATM management architecture, building on a rich heritage of air traffic management research to ensure scalability to meet future needs by taking advantage of emerging trends in digitization, and automation.

Research - Safety

Aviation is on the verge of a significant transformation with the rapid evolution of new technologies, vehicles, and operations on the horizon, while retaining the high standards for safety to which we are accustomed. Maintaining a safe system will require recognition and timely mitigation of safety issues as they emerge, before they become hazards or lead to accidents. A shift toward proactive risk mitigation will become critical to meet these needs. In collaboration with the aviation community, NASA has developed a vision for safety assurance that is achieved by leveraging growing sources of aviation data, commercial data analytics methods, architectures, and the "internet of things" to enable monitoring, prediction, and prognostics capabilities. We are building on previous research to develop the underlying methods, tools and techniques necessary to effectively monitor ongoing operations, assess operations continuously for emerging risks, and provide in-time strategies to mitigate those risks.

In addition to developing technologies to enable in-time monitoring and mitigation of safety hazards, NASA is addressing difficulties associated with assuring the safety of increasingly complex and autonomous aviation systems. We are making available to the broad community improved methods, tools and guidance to support cost-effective paths for achieving the level of safety assurance required for the introduction of highly reliable advanced avionics and future Air Traffic Management (ATM) systems. Industry estimates of costs associated with Verification and Validation (V&V) activities reveal that these costs are becoming unsustainable and have begun to stifle innovation. Current NASA work builds on recent experiments with industry partners and includes development of additional tools and techniques that can reduce the costs and improve effectiveness of V&V, and therefore reduce overall development and certification costs. NASA continues to provide tools and techniques to enable assurance early in the development process, when most errors are introduced, bringing down cost and improving safety coverage. Industry is working with us to evaluate the impact of these new tools and techniques with specific use cases. In addition, we are continuing to provide tools and the guidance to the FAA that can assist in modifying standards and existing certification processes.

Research – vehicles

NASA has provided research results and data on technologies critical for safe integration of unmanned systems into the national airspace, including detect and avoid (DAA) and communications requirements for vehicle command and control (C2). These technologies create a strong foundation for UAM vehicles of the future.

There is growing consensus within the UAM community that critical technologies such as autonomous flight systems and partially or fully electric propulsion systems for vertical take-off and landing, or eVTOL, vehicles will be essential to support safe and cost effective UAM operations.

Data from NASA's electric propulsion research is helping to develop eVTOL and UAM standards. NASA has released extensive data from its X-57 research related to high voltage all-electric powertrains, thus providing a basis for certification standards of electric bus architectures and enabling vehicle developers to start from a common non-proprietary knowledge base. NASA is also researching other aspects of electric propulsion and vehicle architectures which enable vehicles to be designed and operated in entirely new ways. NASA ground test facilities can be used to validate and mature electric propulsion system concepts and vehicle power distribution architectures in simulated flight conditions.

NASA is maturing vehicle design and analysis tools to meet specific UAM applications to address issues such as noise, safety and other operational requirements. For example, NASA's recent acoustic research has demonstrated remarkable achievements in reducing the noise associated with aircraft engines and airframes. This includes the noise that is generated on take-off and landing by the engines, high-lift systems (flaps and slats) and landing gear. Occurring at lower-altitudes, this noise is particularly bothersome to those communities in and around major airports. While these acoustic tools and capabilities have been developed and matured for application to conventional aircraft and operations, they are readily adaptable to the UAM operational space.

Partnerships

NASA is considering opportunities with a wide range of industry partners to conduct these studies, research or joint flight tests to explore UAM concepts and technologies and focus on the most critical challenges.

Through Space Act Agreements, NASA partners with large and small manufacturers to conduct fundamental research, test novel new concepts and technologies, and leverage industry investments to transition advancements from the laboratory into the field.

For example, approximately 40 partner organizations have participated in our UTM Technology Capability Level (TCL) demonstrations, flying their own vehicles and using their own UAS traffic management software interfacing with the NASA UTM system to demonstrate their capabilities in an integrated operational flight test. These TCL demonstrations have enabled companies to prove out their concepts and technologies, and generate data to support future FAA rulemaking.

As one example of what is possible in extending the UAS Traffic Management concept to UAM, NASA is interested in partnering with companies on modeling and simulation of unique airspace requirements for UAM applications. Companies would share with NASA their unique UAM requirements based on their future operational concepts. NASA and the partners would then study airspace management and UAM interactions with traditional air traffic systems through modeling and simulation. For example, through an agreement recently signed with Uber, NASA will use our research facility at Dallas-Fort Worth airport to analyze how Traffic Collision Advisories could be triggered by small passenger-carrying vehicles in an air ride share operational model. We'll also simulate small passenger-carrying vehicles flying into the DFW airspace in the presence of peak scheduled air traffic. The results of this research will be made available to the broader UAM community. These partnerships may be then expanded beyond modeling and simulation to include system-level flight demonstrations, where we can identify and address safety and integration challenges in increasingly crowded airspace.

NASA is interested in exploring such partnerships with a wide range of U.S. commercial companies that are developing a business case in this market as well.

Furthermore, NASA can leverage the UTM federated architecture to enable UTM inspired ATM transformation of the airspace and vehicle management within the National Airspace System.

NASA won't and shouldn't lead all research related to UAM. We will leverage research and technological advances by the private sector or other government agencies in related areas, such as cybersecurity, communications, or vehicle development. There are a host of non-technical challenges which also need to be addressed before a profitable UAM market can flourish, ranging from ground infrastructure development to privacy and security concerns.

There may be opportunities for appropriate engagement with other governments as the aviation community creates standards and certification requirements for UAM vehicles and operations, as they have started to do for civil UAS. We will continue to engage with our U.S. and foreign government partners to understand when the time is right for mutually beneficial collaboration.

UAM Proving Ground

This is a brand new market, and the nature and scope of the biggest obstacles to realizing the market aren't yet fully understood. As mentioned earlier, there are many companies investing heavily in UAM concepts and vehicles, all seeking to be market leaders. However, there is a need for a safe and robust UAM test environment where able participants can bring, integrate, demonstrate and test their capabilities. This will enable them to understand their capability's shortcomings and develop approaches to overcome them without impacting ongoing national airspace system operations. NASA is consulting with the U.S. aviation community through the National Academy of Sciences' Aeronautics Research and Technology Roundtable on establishing the current state-of-the-art for the UAM system-of-systems and achieving early demonstration and learning around the major hurdles that must be overcome. As NASA has learned through its UTM project, establishing a proving ground and running integrated system experiments enables participants to learn their own readiness level and informs an entire community of the overall system-of-system readiness. Therefore, an important element of NASA's strategy is to establish the UAM proving ground and achieve early demonstrations with the community.

US Leadership

In summary, NASA is delivering research results across its current portfolio that will support the development of the Urban Air Mobility market, i.e. UTM Technical Capability Levels (TCLs), UAS in the National Airspace System (NAS) standards, and vehicle technologies.

NASA is committed to maintaining United States aviation leadership in the UAM market space. The U.S. aviation industry has the technology and the spirit of innovation. We have highly capable service providers. And we have the right business environment and entrepreneurial spirit.

However, early signs show us that global competition will be fierce. Companies such as Lilium and Volocopter of Europe are leading global UAM vehicle developers. Foreign governments are eager to be early adopters, wooing U.S. and foreign manufacturers and service providers to test their wares in their countries. As concept demonstrations, Google has been delivering packages in Australia, and Amazon has been delivering them in Iceland. U.S. companies are commercially delivering blood and medical packages in Switzerland and Rwanda. Dubai and New Zealand have supported flight trials of experimental UAM vehicles.

We should not sit by idly and let others reap the benefits of U.S. investment and capabilities. Only together can NASA and the U.S. aviation community define and lead the world into a new future of mobility.