URBAN AIR MOBILITY—ARE FLYING CARS READY FOR TAKE-OFF?

HEARING

BEFORE THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
HOUSE OF REPRESENTATIVES

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TUESDAY, JULY 24, 2018

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, D.C.

The Committee met, pursuant to call, at 10:05 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Lamar Smith [Chairman of the Committee] presiding.

LAMAR S. SMITH, Texas
CHAIRMAN

EDDIE BERNICE JOHNSON, Texas
RANKING MEMBER

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House of Representatives
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Urban Air Mobility – Are Flying Cars Ready for Take-Off?

Tuesday, July 24, 2018
10:00 a.m.
2318 Rayburn House Office Building

<u>Witnesses</u>

Dr. Jaiwon Shin, Associate Administrator, Aeronautics Research Mission Directorate, NASA

Dr. John-Paul Clarke, College of Engineering Dean's Professor, Georgia Institute of Technology; Co-chair, 2014 National Research Council Committee on Autonomy Research for Civil Aviation

Dr. Eric Allison, Head of Aviation Programs, Uber

Mr. Michael Thacker, Executive Vice President, Technology and Innovation, Bell

Ms. Anna Mracek Dietrich, Co-Founder and Regulatory Affairs, Terrafugia

U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HEARING CHARTER

Tuesday, July 24, 2018

TO: Members, Committee on Science, Space and Technology

FROM: Majority Staff, Committee on Science, Space, and Technology

SUBJECT: Full committee hearing: "Urban Air Mobility – Are Flying Cars Ready for Take-Off?"

The Committee on Science, Space, and Technology will hold a hearing titled *Urban Air Mobility – Are Flying Cars Ready for Take-Off?* on Tuesday, July 24, 2018, at 10:00 a.m. in Room 2318 of the Rayburn House Office Building.

Hearing Purpose

The purpose of the hearing is to learn about urban air mobility research and development efforts. The hearing will examine the potential benefits and challenges of 'flying cars' or vertical take-off and landing (VTOL) aircrafts from a public and private sector perspective, including discussion of when such technology may be commercially available.

Witness List

- **Dr. Jaiwon Shin**, Associate Administrator, Aeronautics Research Mission Directorate, NASA
- **Dr. John-Paul Clarke**, College of Engineering Dean's Professor, Georgia Institute of Technology; Co-chair, 2014 National Research Council Committee on Autonomy Research for Civil Aviation
- **Dr. Eric Allison**, Head of Aviation Programs, Uber
- **Mr. Michael Thacker**, Executive Vice President, Technology and Innovation, Bell
- **Ms. Anna Mracek Dietrich**, Co-Founder and Regulatory Affairs, Terrafugia

Staff Contact

For questions related to the hearing, please contact Raj Bharwani of the Majority Staff at 202-225-6371.

Chairman SMITH. The Committee on Space, Science, and Technology will come to order. Without objection, the Chair is authorized to declare recesses of the Committee at any time.

Good morning, and welcome to today's hearing titled "Urban Air Mobility—Are Flying Cars Ready for Take-Off?" I'll recognize myself for five minutes for an opening statement, but before beginning, let me just say that we expect some Members to arrive shortly. There are both Republican and Democratic Caucus meetings going on, and as soon as those caucuses are over, I think that we'll have more Members, although this is a critical mass up here right now.

I also note the good audience interest. Nice to have everybody here and with our discussion about such a fascinating subject. And we welcome our five witnesses as well, and I'll introduce you in just a minute.

For decades, flying cars have been the object of our imagination. They represent aspiration, innovation, and freedom of exploration. The entertainment industry has popularized the concept in everything from Chitty Chitty Bang Bang to The Jetsons, from Star Wars to Back to the Future.

Let me confess to a couple of things this morning. Several weeks ago, I was taking a walk at the Mall, and I noticed a mother with a young son off to the side. It looked like to me the young son was operating a remote-controlled car, and suddenly, wings sprouted from the side of the car and the car took off. This was the first remote-controlled flying car that I've ever seen in my life. But you have to understand that I've been collecting articles about flying cars since I was in elementary school, so I was just absolutely intrigued by what I saw.

I have to say I immediately sent off for one. I flew it in Lincoln Park several weeks ago, and it worked wonderfully. The advantage of this particular remote-controlled car—flying-car plane—is that it flies so slowly you can sort of you can't do much about vertical, but that's okay. It goes so slowly, it doesn't seem to matter.

I also liked it so much that I want to tell Members that I ordered a number of these flying cars. I know a good thing when I see it. Every Member who comes to today's hearing is going to get a flying car, and I am going to show it. This is what the box looks like, and, more specifically, this is what the car looks like when the wings have popped out. This can take off in 15 feet. I could've taken it off on the witness table, but I decided not to because I don't think I could have made the turn before it hit the wall. And I know what everybody would have said if that had happened.

So, in any case, as far as the Members go, we'll be delivering a box to your office sometime today or tomorrow. And I've also promised these flying car models to all the witnesses today, we'll just have to figure out how you get it back if you're not from the DC. area, but we'll figure that out.

By the way, it's always been frustrating to me to be given a present that required batteries and then no batteries, so I have purchased batteries. Will get, taped on top of the model, six AA batteries so that you'll be able to use this car fairly shortly. Anyway, it will be great fun, and I think you'll enjoy it.

By the way, if you want to, be sure and let me know how you did, and if you can do, take a video. Who knows, we may have a video hearing sometime soon. So, anyway, when the word gets out, I suspect we'll have a few more Members come as well. They do have to stay for more than one minute, however.

Let's see. Oh, I want to show you examples of some of these clippings. These are more recent clippings, but the most recent clipping was actually—I'm on a plane Friday night flying back home, and I'm reading The Economist, and in The Economist this week there is an article on flying cars. It's called a "James Bond special," which happens to hit two of my personal interests, both James Bond and the flying cars, but it was in this week's Economist.

Then, we have a Terrafugia witness today, and I went back and I have a clipping from 2010 on the plane that I think you're going to be selling next year. And I was not around at the time, so I don't want any comments, but back in 1945, do you recall the store JCPenney? Okay. This is an ad by JCPenney in 1945, "buy your plane at Penney's." But anyway, it looked like every family was going to own an airplane back then. Obviously, it didn't happen, but that's the kind of aspiration we've had in the United States for—about this subject for a long, long time. So anyway, you can look at my clips whenever you want to.

Let's see. Our focus today is on urban air mobility, a concept that can include delivery drones and personal air vehicles, as well as cars that can both be driven and flown. And advances in lithium-ion battery technology, computing power, and electric propulsion are providing companies with the tools they need to turn science fiction into science fact. This is the first Congressional hearing dedicated to the topic of flying cars.

One company, Terrafugia, says that their vehicle could be available as soon as next year. It's called the Transition and can drive like a car, fit into a standard garage, and be flown in and out of over 5,000 local airports. And Uber has a bold timeline to make an air-based on-demand transportation system available to the public in five years. Companies like Bell are working to design and build the vehicles that will operate on the network envisioned by Uber.

Autonomous cars, which are impressive and already have been the subject of Science Committee hearings, don't have the same benefits as urban air mobility. Traffic and gridlock challenges are better overcome by cars that fly rather than drive. Flying cars also have the benefit of enabling emergency vehicles to reach their destinations faster and provide more mobility options for those who cannot operate a car.

Although it will be a while before we see widespread ownership and use of personal vehicles that can both be driven and flown, these advances are visible on the horizon. As policymakers, we can examine how we can support such technological advances while pursuing a safe, reliable, and efficient regulatory framework.

It occurs to me that we're the first committee in Congress to have a hearing on flying cars, but remember, we were also the first committee to have a hearing on drones and several other subjects as well, so that's one of the things that we are about in the Science Committee, the future and innovation.

We thank our witnesses for being here today, and I look forward to the day when I can fly a flying car.

[The prepared statement of Chairman Smith follows:]

COMMITTEE ON
SCIENCE, SPACE, & TECHNOLOGY
Lamar Smith, Chairman

For Immediate Release
July 24, 2018

Media Contacts: Heather Vaughan, Bridget Dunn
(202) 225-6371

Statement by Chairman Lamar Smith (R-Texas)

Urban Air Mobility – Are Flying Cars Ready for Take-Off?

Chairman Smith: For decades, flying cars have been the object of our imagination. They represent aspiration, innovation and the freedom of exploration.

The entertainment industry has popularized the concept in everything from *Chitty Chitty Bang Bang* to *The Jetsons*, from *Star Wars* to *Back to the Future*.

Several weeks ago, I was walking on the Mall and noticed a boy operating a remote-control flying car—the first one I've ever seen. I immediately sent off for one and flew it recently with a young friend. It exceeded my expectations.

In fact, I liked it so much that I ordered one for each of our witnesses today and for all the Members who attend this hearing.

I've been keeping articles about flying cars since I was in elementary school. Here are some from the last few years.

Just this week there was an article about flying cars in the *Economist* that also mentioned James Bond, so it covered two personal interests!

Our focus today is on Urban Air Mobility (UAM), a concept that can include delivery drones and personal air vehicles as well as cars that can both be driven and flown. (That's different than flying down the highway at high speeds.)

Advances in lithium-ion battery technology, computing power and electric propulsion are providing companies with the tools they need to turn science fiction into science fact.

This is the first congressional hearing dedicated to the topic of flying cars. One company, Terrafugia, says that their vehicle could be available as soon as next year. It's called the *Transition* and can drive like a car, fit into a standard garage, and be flown in and out of over 5,000 local airports.

And Uber has a bold timeline to make air-based on-demand transportation available to the public in five years.

Companies like Bell are working to design and build the vehicles that will operate on the network envisioned by Uber.

Autonomous cars, which are impressive and already have been the subject of Science Committee hearings, don't have the same benefits as Urban Air Mobility.

Traffic and gridlock challenges are better overcome by cars that fly rather than drive.

Flying cars also have the benefit of enabling emergency vehicles to reach their destinations faster and provide more mobility options for those who cannot operate a car.

Although it will be a while before we see widespread ownership and use of personal vehicles that can both be driven and flown, these advances are visible on the horizon.

As policymakers, we can examine how we can support such technological advances while pursuing a safe, reliable and efficient regulatory framework.

We thank our witnesses for being here today. And I look forward to the day when I can take off in a flying car.

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Chairman SMITH. I'll now recognize the Ranking Member Eddie Bernice Johnson, the gentlewoman from Texas, for her opening statement.

Ms. JOHNSON. Thank you very much. Good morning, and let me welcome our witnesses. And thank you, Mr. Chairman, for calling this hearing to examine urban air mobility research and development efforts and the potential benefits and challenges that might accrue from this exciting new technology.

I might say that in the next five years if you'll come to Dallas I will make sure that you get a ride in reality.

Stuck in a traffic jam, who among us has never dreamed of riding a flying car and coming out of that traffic and going—leaping ahead of everybody? Well, it might be on the way. What some of us could only dream of after watching episodes of The Jetsons might actually happen sooner than we think. Indeed, we will hear today many companies believe that we are in the threshold of revolutionary changes brought about by a new generation of vehicles.

A multitude of concepts for vertical takeoff and landing vehicles, many of them fueled by recent advances in lightweight electric propulsion and storage capacity, are being proposed with the goal of providing convenient urban transportation. Washington, you know, can really use this, too, especially where I have to go and come from home.

If proven to be safe, such concepts could result in changing the way goods are delivered and people move around. In turn, the innovation generated by UAM may result not only in creating new jobs but also enhancing the productivity of workers in existing jobs.

But as with any new technology, there are challenges to its implementation. This calls for thoughtful examination. A panel established by the National Academies found in 2014 that, increasingly, autonomous aircraft pose serious questions about how they will be safely and efficiently integrated into the existing civil aviation structure.

As defined by the panel, a fully autonomous aircraft would not require a pilot. The aircraft would be able to operate independently within civil airspace, interacting with air-traffic controllers and other pilots, just as if a human pilot were on board and in command.

In addition to technological barriers such as accurately predicting the behavior of systems that can adapt to changing conditions, a feature critical in autonomous aircraft, widespread operation of UAS systems will also require resolution of applicable regulatory and certification requirements. Regulations are needed to ensure that vehicles can operate in airspace above cities without negatively impacting safety. In addition, certification and safety requirements for these type of vehicles would need to be developed.

Finally, a major challenge will be integrating UAM operations into the national airspace. In that regard, we are fortunate that we can leverage NASA's work on the unmanned aircraft system, or the UAS, traffic management to get a head start examining the issue.

Mr. Chairman, I look forward to the—hearing from our witnesses on the benefits and challenges associated with UAM operations and on the role research can play in enhancing the safety of future UAM operations.

And I yield back.

[The prepared statement of Ms. Johnson follows:]

OPENING STATEMENT
Ranking Member Eddie Bernice Johnson (D-TX)

House Committee on Science, Space, and Technology
"Urban Air Mobility – Are Flying Cars Ready for Take-Off?"
July 24, 2018

Good morning, and welcome to our witnesses.

Mr. Chairman, thank you for calling this hearing to examine Urban Air Mobility research and development efforts and the potential benefits and challenges that might accrue from this exciting new technology.

Stuck in a traffic jam, who among us has never dreamed of riding in a "flying car" to lift us high above city congestion and leap frog other cars in our way? Well, what some of us could only dream of after watching episodes of the Jetsons might actually happen sooner than we think. Indeed, as we will hear today, many companies believe that we are on the threshold of revolutionary changes brought about by a new generation of vehicles.

A multitude of concepts for vertical take-off and landing vehicles, many of them fueled by recent advances in lightweight electric propulsion and storage capability, are being proposed with the goal of providing convenient urban transportation. If proven to be safe, such concepts could result in changing the way goods are delivered and people move around. In turn, the innovation generated from UAM may result not only in creating new jobs, but also in enhancing the productivity of workers in existing jobs. But as with any new technology, there are challenges to its implementation. This calls for a thoughtful examination.

A panel established by the National Academies found in 2014 that increasingly autonomous aircraft "*pose serious questions about how they will be safely and efficiently integrated into the existing civil aviation structure*". As defined by the panel, a fully autonomous aircraft would not require a pilot. The aircraft would be able to operate independently within civil airspace, interacting with air traffic controllers and other pilots just as if a human pilot were on board and in command. In addition to technological barriers such as accurately predicting the behavior of systems that can adapt to changing conditions, a feature critical in autonomous aircraft, widespread operation of UAM systems will also require resolution of applicable regulatory and certification requirements. Regulations are needed to ensure that vehicles can operate in airspace above cities without negatively impacting safety. In addition, certification and safety requirements for these types of vehicles will need to be developed.

Finally, a major challenge will be integrating UAM operations into the national airspace. In that regard, we are fortunate that we can leverage NASA's work on its Unmanned Aircraft System

(UAS) Traffic Management to get a head start examining this issue. Mr. Chairman, I look forward to hearing from our witnesses on the benefits and challenges associated with UAM operations and on the role research can play in enhancing the safety of future UAM operations.

With that final note, I yield back.

Chairman SMITH. Thank you, Ms. Johnson.

Let me introduce our experts today. And our first witness is Dr. Jaiwon Shin, Associate Administrator of the Aeronautics Research Mission Directorate at NASA. In this role, Dr. Shin manages the agency's aeronautics research portfolio and guides its strategic direction, including research in advanced air vehicle concepts, airspace operations, safety integrated aviation systems and the development of aviation concepts.

Prior to working at NASA headquarters, Dr. Shin served as Chief of the Aeronautics Projects Office at NASA's Glenn Research Center, where he managed all of the Center's aeronautics projects.

Dr. Shin received a bachelor's degree from Yonsei University in Korea, a master's degree in mechanical engineering from California State University, and a Ph.D. in mechanical engineering from Virginia Tech University.

Our second witness is Dr. John-Paul Clarke, the College of Engineering Dean's Professor at the Georgia Institute of Technology, and the Co-Chair of the 2014 National Research Council Committee on Autonomy Research for Civil Aviation. Dr. Clarke's main areas of research include aircraft trajectory prediction and optimization, especially as it pertains to the development of flight procedures that reduce the environmental impact of aviation.

Dr. Clarke received his Bachelor of Science, Master of Science, and Doctorate of Science degrees from MIT. Apparently, you like Cambridge.

Our third witness today is Dr. Eric Allison, Head of Aviation Programs at Uber. Prior to Uber, Dr. Allison served as CEO of Zee Aero, where he led the development of the Cora vehicle, a two-place, self-piloted air taxi.

Dr. Allison received a Bachelor of Arts in mechanical engineering from the Milwaukee School of Engineering. He also earned a Master of Science and Ph.D. from the Department of Aeronautics and Astronautics at Stanford University.

Our fourth witness is Mr. Michael Thacker, Executive Vice President of Technology and Innovation at Bell. In this role, Mr. Thacker is responsible for leading Bell's engineering team and providing strategic direction for designing, developing, and integrating technologies. Prior to Bell, Mr. Thacker served as a Senior Vice President of Engineering at Textron Aviation.

Mr. Thacker holds a bachelor of science in aerospace engineering and a Master of Science from Kansas University. He also holds an MBA degree from Duke University.

Our final witness is Ms. Anna Mracek Dietrich, Co-Founder and Regulatory Affairs at Terrafugia. She leads Terrafugia's U.S. regulatory policy engagement.

Prior to founding Terrafugia, Ms. Dietrich worked to advance pioneering strategies and product development at GE Aviation and Boeing Phantom Works. As a recognized leader in aviation and innovation, she was named one of Boston's top 15 innovators by the Boston Globe.

Ms. Dietrich earned bachelor and Master of Science degrees in aerospace engineering from MIT, and also holds a private pilot license.

We welcome you all, and look forward to your testimony. Dr. Shin, if you'll begin.

TESTIMONY OF DR. JAIWON SHIN, ASSOCIATE ADMINISTRATOR, AERONAUTICS RESEARCH MISSION DIRECTORATE, NASA

Dr. SHIN. Chairman Smith, thanks so much for that great opening.

Ranking Member Johnson and Members of the Committee, thank you for this opportunity to testify on NASA's aeronautics research program and the R&D challenges related to urban air mobility, or UAM.

NASA's aeronautics is globally recognized as the DNA of the aviation system. For over 100 years, we have been conducting world-class research to enable safer, more efficient, and more environmentally friendly air transportation systems. We work through collaborative partnerships with the U.S. aviation industry, other government agencies, and academia to ensure our technologies quickly transition for application.

As the introduction of the jet engine revolutionized aviation in the last century, UAM promises another revolution in this century. This new capability could completely transform the urban landscape and change our lifestyle. Urban air mobility is not a new idea, but in the past, the technologies were not available to meet the safety and economic requirements.

So what's different now? First, the enabling technologies are within our grasp such as an ability to manage massive data sets; electric power and propulsion systems for quiet, sustainable, and more affordable vehicles; miniaturization and fusion of sensors in vehicle and operational system autonomy.

Second, by the middle of the century, 70 percent of the world population will live in urban areas. Mobility within these cities will require different solutions.

Finally, there is a change in consumer expectations. Across society, we are bringing technology to end-users on demand and at their fingertips. Now, technology can enable the same on-demand experience in aviation.

But this new market won't emerge overnight. UAM will start with a mix of onboard-piloted and remotely piloted vehicles and progress toward autonomous operations. Markets will develop incrementally with initial markets driven by the need to have a solid safety case. Along the way, many challenges will need to be solved.

NASA focuses on the critical technical challenges where no one company can go alone. And NASA is already contributing. We have recently made history by flying our Ikhana UAS without a chase aircraft utilizing the standards that we developed and validated. We innovated the UAS traffic management or UTM concept for smaller UAS to operate at low altitude in uncontrolled airspace. Today, UAM is accepted concept around the world.

Through our general aviation size X–57 distributed electric propulsion demonstrator, we are helping to develop and validate standards and means of certifying electric propulsion components and systems. But UAM presents many more challenges in technical regulatory policy and infrastructure areas. Prevailing UAM vehicle concepts employ vertical takeoff and landing designs that utilize distributed electric propulsion systems and highly automated guidance and control systems. Assuring the safety of these vehicles for operation in densely populated urban areas will be a major challenge.

To enable UAM operations of distributed highly automated service provider-based system with robust data-sharing is needed, which is precisely what NASA is developing today with UTM. We will extend the UTM concept to meet the even more challenging UAM requirements.

Communities will not accept UAM operations if the noise level significantly exceeds background noise levels. Meeting those expectations requires technologies to reduce vehicle noise and mitigate noise through operational procedures. NASA is uniquely positioned to make impactful contributions to realizing the UAM vision by providing leadership in identifying the key challenges and conducting necessary R&D to address those challenges. We are actively shifting our focus to work on these challenges, building new partnerships, and leveraging ongoing work to make an impact as soon as possible.

UAM is a major economic and transportation opportunity that the United States must lead. NASA will do our best to ensure the United States maintains the global leadership. With the right technology, right business environment, and entrepreneurial spirit to succeed, NASA and the U.S. aviation community will lead the world into a new era of aviation.

Thank you again for this opportunity to testify on this critically important topic. I look forward to answering your questions.

[The prepared statement of Dr. Shin follows:]

National Aeronautics and
Space Administration

Hold for Release Until
Presented by Witness

July 24, 2018

Committee on Science, Space, and Technology

U.S. House of Representatives

Statement by:
Dr. Jaiwon Shin
Associate Administrator
Aeronautics Research Mission Directorate

115th Congress

HOLD FOR RELEASE
UNTIL PRESENTED
BY WITNESS
July 24, 2018

Statement of

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

before the

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

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.

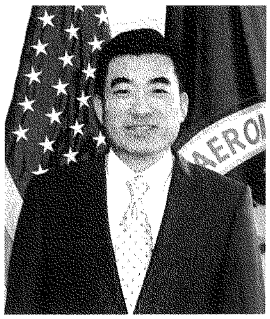
US Leadership

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.



Dr. Jaiwon Shin is the associate administrator for the Aeronautics Research Mission Directorate (ARMD), a position which he has held since 2008. Shin manages the agency's aeronautics research portfolio and guides its strategic direction, including research in advanced air vehicle concepts, airspace operations and safety, integrated aviation systems, and the nurturing and development of transformative concepts for aviation.

Shin co-chairs the National Science & Technology Council's Aeronautics Science & Technology Subcommittee whose charter is to facilitate coordination and collaboration among the federal departments and agencies that fund aeronautics-related research. The subcommittee wrote the nation's first presidential policy for aeronautics research and development (R&D). The policy was established by Executive Order 13419 in December 2006 and will guide U.S. aeronautics R&D programs through 2020.

He is a past chair of the International Forum for Aviation Research, the world's only aviation research establishment network, with 26 member countries that seeks to connect research organizations and enable information exchange on aviation challenges of common interest.

Between May 2004 and January 2008, Shin served as deputy associate administrator for the ARMD, where he was instrumental in restructuring NASA's aeronautics program to focus on fundamental research and better align with the nation's Next Generation Air Transportation System (NextGen).

Prior to coming to work at NASA Headquarters, Shin served as chief of the Aeronautics Projects Office at NASA's Glenn Research Center. In this position he managed all of the center's aeronautics projects. Prior to this, he was Glenn's deputy director of aeronautics, where he provided executive leadership for the planning and implementation of Glenn's aeronautics program, and interfaced with NASA Headquarters, other NASA centers, and external customers to explore and develop technologies in aeropropulsion, aviation safety and security, and airspace systems.

Between 1998 and 2002, Shin served as chief of the Aviation Safety Program Office, as well as the deputy program manager for NASA's Aviation Safety Program, and Airspace Systems Program. He assisted both program directors in planning and research management.

His honors include the 2008 Presidential Rank Award for Meritorious Senior Executive, NASA's Outstanding Leadership Medal, NASA's Exceptional Service Medal, a NASA Group Achievement Award, Lewis Superior Accomplishment Award, three Lewis Group Achievement Awards, and an Air Force Team Award. He is a graduate of the Senior Executive Fellowship Program at the Kennedy School of Government at Harvard University. He has extensive experience in high speed research and aircraft icing, and has authored or co-authored more than 20 technical and journal papers.

Shin received his doctorate in mechanical engineering from the Virginia Polytechnic Institute and State University, Blacksburg, Virginia. His bachelor's degree is from Yonsei University in Korea and his master's degree is in mechanical engineering from the California State University, Long Beach.

Chairman SMITH. Thank you, Dr. Shin.
And Dr. Clarke?

TESTIMONY OF DR. JOHN-PAUL CLARKE, COLLEGE OF ENGINEERING DEAN'S PROFESSOR, GEORGIA INSTITUTE OF TECHNOLOGY; CO-CHAIR, 2014 NATIONAL RESEARCH COUNCIL COMMITTEE ON AUTONOMY RESEARCH FOR CIVIL AVIATION

Dr. CLARKE. Chairman Smith, Ranking Member Johnson, Members of the Committee, thank you for this opportunity to comment on the potential benefits and challenges of urban air mobility.

The subject vision for UAM is that of vertical takeoff and landing and in some cases short takeoff and landing vehicles transporting people directly between their origins and their destinations. However, there's also an equally compelling vision of VTOL vehicles, potentially autonomous VTOL vehicles transporting packages and cargo on nonstop segments between their origins and destinations.

My sense is that UAM will involve the movement of both people and cargo between origins and destinations and that it's also very likely that they will have to be a dynamic hub-and-spoke network in a similar way to we have airlines where flight segments and the locations of hubs are dynamically generated based on the demand that you see at any given time.

With this vision as a basis for analysis, it's evident to me that, first, aircraft will require greater autonomy in operations, and by that I mean be able to operate without human intervention, supervision, and autonomous decision-making, i.e., able to determine what to do next in a situation that was not preprogrammed or predetermined.

Second, the two basic aspects of air-traffic management, air-traffic control and traffic flow management, will also require greater autonomy.

Third, the proliferation of vertiports will raise noise, privacy, and safety concerns.

Fourth, vertiport locations and flight trajectories must be jointly optimized for efficiency, noise, privacy, and safety.

Fifth, ATM for UAM will likely be provided by private/municipal entities, maybe public-private partnerships that are monitored or regulated by the FAA.

And sixth, legislation may be needed with respect to certification requirements for vehicles, systems, and operators.

The first two issues I've raised relate to autonomy. The third and fourth issues relate to modeling and optimization. The fifth and sixth are public policy issues for which I am not an expert but I am sure many in the room are. Thus, I will confine the remainder of my remarks to the research challenges and objectives for autonomy research and for modeling and optimization research.

With regards to autonomy research, in 2014 the NRC report entitled "Autonomy Research for Civil Aviation: Towards a New Era of Flight," my colleagues and I identified eight technical barriers, four regulation and certification barriers, and two legal and social barriers to increased autonomy.

We propose the following four most urgent and most difficult research projects: develop methodologies to characterize and bound the behavior of adaptive nondeterminate systems over their complete lifecycle; two, develop the system architectures and techniques that would enable increasingly sophisticated and increasingly autonomous systems and unmanned aircraft to operate for extended periods without real-time human cognizance or control; three, develop the theoretical basis and methodologies for using modeling and simulation to accelerate the development and maturation of advanced increasingly autonomous systems and aircraft; and fourth, develop standards and processes for verification, validation, and certification of increasingly autonomous systems and determine their implications for design.

I believe that these research projects remain relevant to the quest for increasing the autonomous vehicles and systems and are just as relevant to the realization of UAM. To my knowledge NASA has started research in each of these four areas. However, progress has been slow and needs to be accelerated.

In regards to modeling and optimization research, helicopter noise has been and continues to be a concern in urban areas. I have every reason, given the similarities, to believe that the noise from proposed UAM VTOL will also be a concern in urban areas. Separately, there continues to be concern about safety of helicopters and other rotorcraft, and current understanding of the privacy and safety concerns of the general public is poor.

With these considerations in mind, I believe that UAM will be further enabled by investments in the following four research projects:

First, develop models for source noise and failure characteristics of a wide range of proposed vehicles in a wide range of operating conditions.

Second, develop noise and failure modeling frameworks that can be used in the context of a broader vehicle design tool to develop no-noise, high-reliability vehicles and to aid in certification.

Third, develop holistic analytics capabilities for UAM.

Fourth, develop high-fidelity computationally efficient algorithms to optimize trajectories and the locations of vehicles.

Thank you for inviting me to testify and for having the vision to hold a hearing on this very important topic. I look forward to your questions and to working with you in the future on this topic.

[The prepared statement of Dr. Clarke follows:]

Statement of

Dr. John-Paul Clarke
College of Engineering Dean's Professor, Georgia Institute of Technology
Co-Chair, 2014 National Research Council Committee on Autonomy Research for Civil Aviation

before the

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

24 July 2018

Chairman Smith, Ranking Member Johnson and Members of the Committee:

Thank you for the opportunity to comment on the potential benefits and challenges of Urban Air Mobility (UAM). I am a College of Engineering Dean's Professor at the Georgia Institute of Technology, where I have a joint appointment in the School of Aerospace Engineering and the School of Industrial and Systems Engineering, and am Director of the Air Transportation Laboratory. Of further relevance to my testimony, I was Co-Chair of the 2014 National Research Council Committee on Autonomy Research for Civil Aviation. That said, I should note that while my testimony is informed by my participation on that Committee, I am speaking as an individual today.

Overview

UAM is a logical response to the perennial quest for speed in congested urban areas. In the latter half of the 19th century, we satisfied this need for speed in cities such as London and New York by going underground. In the early 21st century, when surface and underground transportation modes are reaching their limits, and the costs of additional infrastructure are prohibitive, we are seeking to satisfy this need for speed by moving to the air. Rather than focus on the speed and other benefits afforded by UAM, I would like to focus my remarks on the challenges that need to be overcome, and the research that must be conducted to enable UAM.

The subject vision for UAM is that of Vertical Take-Off and Landing (VTOL) or Short Take-Off and Landing (STOL) aircraft transporting people directly (i.e., on non-stop flight segments) from their origin to their destination. However, there is an equally compelling vision of VTOL aircraft transporting packages and cargo on non-stop flight segments between their origins and destinations. If both visions are fully realized, there will certainly be a great many aircraft flying along roads and between buildings in the urban setting—more so because a point-to-point service network requires significantly more aircraft than a hub-and-spoke network.

My sense is that UAM will ultimately involve the movement of both people and cargo between their origins and destinations, and it will very likely also require a dynamic hub-and-spoke network, i.e., where flight segments and the location of hubs are dynamically generated based on demand to achieve the desired economies of scale. With this vision as a basis for analysis, it is evident to me that:

1. Aircraft will require greater autonomy.

   If the most-optimistic growth scenarios are realized, and at least one operator is required in each aircraft, we won't be able to train the requisite numbers of operators to the typical skill level of pilots. Further, from the perspective of commercial operations, there is a forecast shortage of commercial pilots, and the economies of scale do not support the employment of multiple operators or operators that are trained and thus compensated at the same rates as commercial pilots. Thus, both passenger and cargo aircraft must be designed for both autonomous operations (i.e., without continuous human participation or supervision) and autonomous decision-making (i.e., able to determine what to do next in an unscripted situation without needing to consult a human) if they are to have a single operator or operators with significantly less training than commercial pilots.

If, on the other hand, aircraft are operated remotely, there could be time delays between the operator and the aircraft (due to the distance between them) and periodic loss of communication (due to line of sight blockage by buildings). Periodic loss of communication is especially problematic when aircraft are operating near each other, near people and objects on the ground, and in an environment with rapidly changing wind conditions (due to wind gusts generated by buildings). Thus, remotely operated aircraft must also be designed for both autonomous decision-making and autonomous operations.

2. The two basic aspects of Air Traffic Management (ATM), i.e., Air traffic control (ATC) and Traffic flow management (TFM) will require greater autonomy.

   If the most optimistic growth scenarios are realized, ATC—the detection and resolution of potential conflicts—will not be possible via human command and control because, when significant numbers of vehicles are operating in a constrained and rapidly changing environment, conflict detection and resolution must be conducted more precisely and rapidly, and will at the very least require automated systems that can operate autonomously. In addition, the number of air traffic controllers required to accommodate a large fleet of UAM aircraft would not be affordable. Further, because the automation cannot simply hand ATC over to a human when faced with a situation that was not considered when it was designed, the automation must also be capable of autonomous decision-making.

   Separately, TFM—the forecasting and regulation of the number of aircraft entering a specific volume of airspace—will not be possible with human-in-the-loop decision-making. At an airport, there is airspace available for airborne holding and remote areas on the surface to hold and park aircraft. At an urban/metropolitan vertiport, there is less airspace available for airborne holding, and few or no remote areas on the surface to hold or park aircraft. During periods of high traffic demand, the scheduling and management of vertiport arrivals and departures must be more precise and timely than currently possible, and will also require automated systems that can operate autonomously.

3. The proliferation of vertiports will raise noise, privacy, and safety concerns.

   In most visions for UAM, aircraft are either helicopters or propeller-based aircraft that use their propellers to achieve VTOL, and they take-off from and land at locations near where people "want to be," e.g., near their homes. Locations near the homes of passengers and the recipients of packages will also be near the homes of other residents who might not be as receptive to noise emanating from rotating blades/propellers. Further, the proximity of the aircraft to windows and backyards is likely to raise issues with respect to privacy, and in virtually all locations there will be concerns with respect to safety.

4. Vertiport locations and flight trajectories must be jointly optimized for efficiency, noise, privacy, and safety.

   The noise generated by helicopters, and other aircraft that use propellers to achieve VTOL, is dominated by the shock waves from the tips of the rotating blades, and blade vortex interaction (BVI) the additional noise that is generated when a propeller blade moves through the wake from another propeller blade. Noise in general can be reduced by moving the noise source further away from the receiver, and/or by shielding the receiver from direct exposure to the noise source, e.g., by placing the vertiport behind or between buildings where no noise-sensitive activities are conducted. BVI can be reduced by optimizing the arrival (descent) and departure (ascent) trajectories. Thus, joint optimization of vertiport locations and flight trajectories can play an important role in reducing community objections to UAM operations based on noise.

   Joint optimization of vertiport locations and flight trajectories can also play an important role in terms of efficiency, privacy, and safety. With regards to efficiency, the energy and time expended during arrival and departure is a function of the distance to the vertiport and the trajectory flown. So too are the distances to and the ability to observe activities in the homes of other residents. With regards to safety, consideration and analysis of post-failure operations is a critical part of aviation. Fixed-wing aircraft are only allowed to take-off after the pilot (or dispatcher) has shown via computation that they can either abort or continue to take-off after one engine has failed. Commercial aircraft are only allowed to fly on a given route after it has been determined that the aircraft type in question will be able to land at an airport if one engine were to fail at any point along that route. Thus, given the proximity of these aircraft to each other, and to people and objects on the ground, accident risk must also be considered when determining the locations of vertiports and designing flight trajectories.

5. ATM for UAM will likely be provided by private/municipal entities that are monitored/regulated by the FAA.

   If the history of aviation is a guide, air traffic operations in each urban/metropolitan area will be managed independently of operations in other urban/metropolitan areas. Further, in the case of UAM, where for the most part it is envisioned that the new VTOL aircraft will use lower operating altitudes and different airspace than conventional aircraft, it is very likely that regions within an urban/metropolitan area will be managed independently. While it certainly is possible to expand the operational side of the FAA to provide ATM services for UAM, it seems more likely, given the enthusiasm for UAM, that some sort of public-private partnership will be formed between private and municipal entities, and that the FAA will play a regulatory role.

6. Legislation may be needed with respect to certification requirements for vehicles, systems, and operators.

   Manufacturers of aviation vehicles and systems, and the operators of these vehicles and systems, receive an implicit, and in some cases, explicit reduction in liability once they have completed lengthy and rigorous evaluations, and have satisfied very stringent certification requirements. While shorter evaluation periods would be beneficial with respect to enabling the envisioned growth in UAM, there may be negative implications with respect to liability. Thus, careful consideration must be given to how best to reduce certification requirements and time commitments without imposing onerous liabilities on manufacturers and operators.

The first two issues I have raised relate to autonomy. The third and fourth issues relate to modeling and optimization. The fifth and sixth are public policy issues, for which I am not an expert. Thus, I will confine the remainder of my remarks to the research challenges and objectives for autonomy research, and for modeling and optimization research.

Autonomy Research

In the 2014 NRC report entitled "Autonomy Research for Civil Aviation—Toward a New Era of Flight" my colleagues and I identified eight technical barriers, four regulation and certification barriers, and two legal and social barriers to increased autonomy in civil aviation. Paraphrasing the wording from that report, these barriers are:

Technology Barriers

- Excessive demand for data and communications bandwidth
- Vulnerability to cyber-physical attacks
- Need for backward compatibility with diverse legacy vehicles
- Need for humans and machines to work together in new and different ways
- Lack of generally accepted methods for "handling" adaptive/nondeterministic systems
- Limited machine sensing, perception, and cognition capabilities
- High system complexity and low resilience (thereby allowing failures in one part of the system to easily propagate throughout the system)
- Insufficient methods for verification and validation

Regulation and Certification Barriers

- Unmanned aircraft requiring a certificate of authorization to operate in non-segregated airspace
- Certification criteria and processes that do not consider the characteristics of advanced autonomy
- Safety standards and requirements that are not well suited to unmanned aircraft operations
- Inability to engender trust in adaptive/nondeterministic increasingly autonomous systems

Legal and Social Barriers

- Public policy (i.e., law and regulation) impeding the degree and speed of adoption of autonomy
- Public concerns about privacy and safety impeding the degree and speed of adoption of autonomy

While we did not individually prioritize these barriers, we did identify four barriers that were particularly onerous with respect to meeting the key challenge, which is "How can we assure that advanced increasingly autonomous systems—especially those systems that rely on adaptive/nondeterministic software—will enhance rather than diminish the safety and reliability of the National Airspace System?" We also proposed the following four "most urgent and most difficult" research projects:

1. Develop methodologies to characterize and bound the behavior of adaptive/nondeterministic systems over their complete life cycle.

2. Develop the system architectures and technologies that would enable increasingly sophisticated and increasingly autonomous systems and unmanned aircraft to operate for extended periods of time without real-time human cognizance and control.

3. Develop the theoretical basis and methodologies for using modeling and simulation to accelerate the development and maturation of advanced, increasingly autonomous systems and aircraft.

4. Develop standards and processes for the verification, validation, and certification of increasingly autonomous systems and determine their implications for design.

I believe that these research projects remain relevant to the quest for increasingly autonomous vehicles and systems, and are relevant to the realization of UAM. To my knowledge, NASA has started research in each of these four areas. However, progress has been slow, and needs to be accelerated.

Modeling and Optimization Research

Helicopter noise has been and continues to be a concern in urban areas. This is evident in New York City—where helicopter route changes have been made to address noise concerns and the City has mandated a 50% reduction in air tour flights in 2016 (after proposing a full ban)—and in Washington, D.C.—where the Department of Defense has been directed to study the effects of military helicopter noise on the National Capital Region and develop recommendations for the reduction of its effects. This is also evident in Los Angeles—where the Secretary of Transportation has been directed to evaluate and adjust helicopter routes and altitudes to lessen noise impacts, develop and promote best practices for hovering and electronic news gathering, and work with local stakeholders to raise awareness and develop a more comprehensive noise complaint system.

Given the similarities, I have every reason to believe that the noise from the proposed UAM VTOL aircraft will also be a concern in urban areas. That said, while the source noise characteristics of helicopters have been well studied, the source noise characteristics of many of the proposed aircraft designs are not well known. Further, even though research has shown that humans perceive aircraft to be noisier when they are closer and the perceived/actual risk is greater, current understanding of the response of communities to rotor/propeller noise from nearby VTOL operations is poor. Thus, there is currently no model that can accurately predict what the noise impact will be after the proposed VTOL aircraft have been introduced into service.

Separately, there continue to be concerns about the safety of helicopters and other rotorcraft. In addition, joint optimization of vertiport locations and flight trajectories for efficiency, noise, privacy, and safety is a very difficult large-scale multi-objective optimization problem, and current understanding of privacy and safety concerns is poor. Thus, there is a need for new or enhanced noise models, and better understanding of privacy and risk thresholds to enable the design of new aircraft, the optimal placement of vertiports, and the optimal design of flight trajectories.

To my knowledge, the FAA and NASA are individually and jointly conducting or funding several research projects to: (1) better understand the response of communities to helicopter noise; and (2) develop low-noise operational procedures and guidance for helicopters. I know of no parallel research efforts at the FAA with respect to the proposed VTOL aircraft. NASA is conducting fundamental research to characterize the noise generated by various configurations, the human perception of this noise, and how the phasing of multiple rotors might be optimized along with the trajectory to direct noise to non-sensitive locations. NASA is also conducting limited fundamental research on modeling and predicting the failure of novel VTOL aircraft.

With these considerations in mind, I believe that UAM will be further enabled by investment in the following four research projects:

1. Develop models for the source noise and failure characteristics of a wide range of proposed UAM aircraft in a representative range of operating conditions.

2. Develop noise and failure modeling frameworks that can be used within the context of a broader vehicle design tool to design low-noise high-reliability vehicles, and to aid in certification.

3. Develop holistic analysis capability for UAM that enables estimation of appropriate measures of operational efficiency, noise impact, privacy, and risk.

4. Develop high-fidelity, computationally efficient algorithms and tools for the joint optimization of vertiport locations and flight trajectories.

Concluding Remarks

Thank you for inviting me to testify and for having the vision to hold a hearing on this important topic. I look forward to your questions and to working with you after this hearing as you continue your work related to Urban Air Mobility.

John-Paul Clarke is a College of Engineering Dean's Professor at the Georgia Institute of Technology, where he has appointments in Aerospace Engineering and Industrial and Systems Engineering, and serves as Director of the Air Transportation Laboratory.

Dr. Clarke's research in aircraft trajectory prediction and optimization, especially as it pertains to the development of flight procedures that reduce the environmental impact of aviation, has been instrumental in changing both the theory and the practice of flight procedure design. More broadly, his research focuses on the development and use of stochastic models and optimization algorithms to improve the efficiency and robustness of aircraft, airline, airport, and air traffic operations.

Professor Clarke was co-Chair of the National Academies Committee that developed the US National Agenda for Autonomy Research related to Civil Aviation, and a member of the National Academies Committee that reviewed the Next Generation Air Transportation System. He is currently co-Chair of the Joint Planning Committee for the AIAA-AAAF Aviation Noise and Emissions Reduction Symposium (ANERS) and a member of the NASA Advisory Council Aeronautics Committee. Over the years, he has chaired or served on advisory and technical committees chartered by the AIAA, EU, FAA, ICAO, NASA, the National Academies, the US Army, and the US DOT.

Dr. Clarke received the S.B., S.M., and Sc.D. degrees from the Massachusetts Institute of Technology (MIT) in 1991, 1992, and 1997, respectively. His many prior honors include the 1999 AIAA/AAAE/ACC Jay Hollingsworth Speas Airport Award, the 2003 FAA Excellence in Aviation Award, the 2006 National Academy of Engineering Gilbreth Lectureship, the 2012 AIAA/SAE William Littlewood Lectureship, and the SAE Environmental Excellence in Transportation Award in 2015. He is a Fellow of the AIAA, and is a member of AGIFORS, INFORMS, and Sigma Xi.

Chairman SMITH. Thank you, Dr. Clarke.
Dr. Allison?

TESTIMONY OF DR. ERIC ALLISON, HEAD OF AVIATION PROGRAMS, UBER

Dr. ALLISON. Mr. Chairman, Ranking Member Johnson, and Members of the Committee, it is a privilege to be here before you today to discuss the role Uber will play in delivering aerial-ride sharing services in the years ahead. My name is Eric Allison, and I'm excited to lead Uber's Elevate initiative. Elevate is building our future Uber air product that aims to allow anyone to push a button and get a flight. To achieve this, we are developing a real-time on-demand network of air vehicles to deliver time savings to riders on a massive scale.

We are creating Uber Air because we believe aerial ridesharing has the potential to radically improve urban mobility. Every year, millions of hours are wasted in traffic on roads worldwide. In 2016, the Texas Department of Transportation estimated drivers in five of the State's largest metropolitan areas lose about 52 hours a year due to congestion. And here in the United States we have one of the world's most congested cities, Los Angeles. This is why we have announced Dallas-Fort Worth and Los Angeles as two of our launch markets. For residents of these cities and for the rest of us, moments stuck on the road represent less time with family, fewer hours growing our economies, and more money spent polluting the world.

As a multimodal transportation company, Uber believes solving this problem is core to our mission of making transportation safe, reliable, and affordable to everyone everywhere. Just as skyscrapers allowed cities to use limited land more efficiently, urban air transportation will use all three dimensions to alleviate transportation congestion on the ground.

We started this journey two years ago by publishing our Elevate white paper, which I respectfully request be entered into the record.

Chairman SMITH. Without objection, the white paper will be made a part of the record.

[The information follows:]

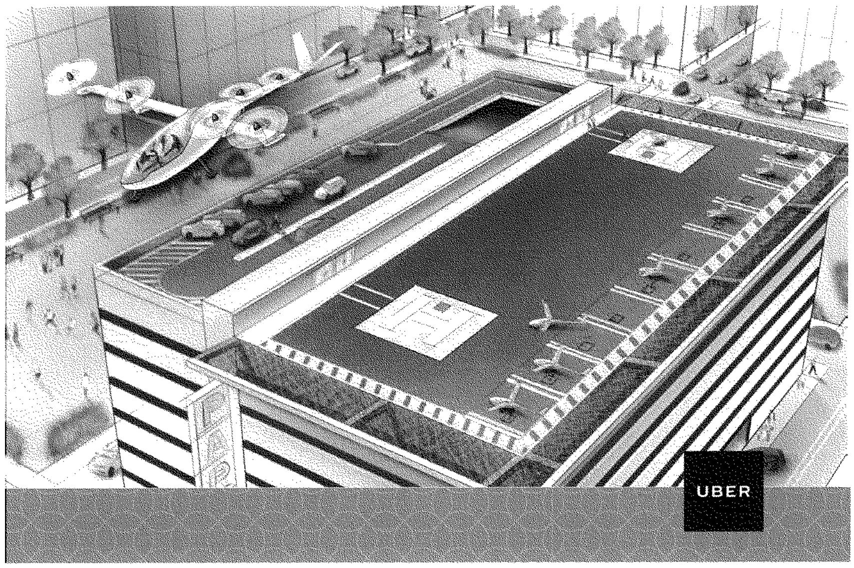
Uber white paper:

Title: *Fast-Forwarding to a Future of On-Demand Urban Air Transportation*

Published By: UBER Elevate

Date: October 27, 2016

https://www.uber.com/elevate.pdf



UBER Elevate

Fast-Forwarding to a Future of On-Demand Urban Air Transportation

October 27, 2016

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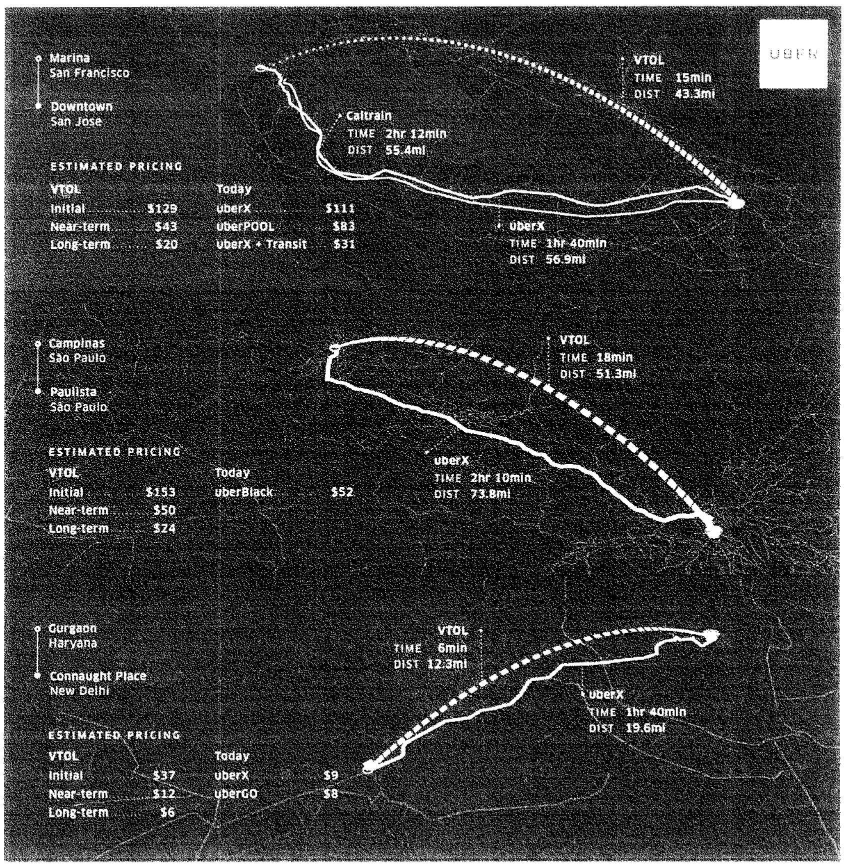
Introduction

Imagine traveling from San Francisco's Marina to work in downtown San Jose—a drive that would normally occupy the better part of two hours—in only 15 minutes. What if you could save nearly four hours round-trip between São Paulo's city center and the suburbs in Campinas? Or imagine reducing your 90-plus minute stop-and-go commute from Gurgaon to your office in central New Delhi to a mere six minutes.



Every day, millions of hours are wasted on the road worldwide. Last year, the average San Francisco resident spent 230 hours commuting between work and home[1]—that's half a million hours of productivity lost every single day. In Los Angeles and Sydney, residents spend seven[1] whole working weeks each year commuting, two of which are wasted unproductively stuck in gridlock[2]. In many global megacities, the problem is more severe: the average commute in Mumbai[3] exceeds a staggering 90 minutes. For all of us, that's less time with family, less time at work growing our economies, more money spent on fuel—and a marked increase in our stress levels: a study in the *American Journal of Preventative Medicine*, for example, found that those who commute more than 10 miles were at increased odds of elevated blood pressure[4].

On-demand aviation, has the potential to radically improve urban mobility, giving people back time lost in their daily commutes. Uber is close to the commute pain that citizens in cities around the world feel. We view helping to solve this problem as core to our mission and our commitment to our rider base. Just as skyscrapers allowed cities to use limited land more efficiently, urban air transportation will use three-dimensional airspace to alleviate transportation congestion on the ground. A network of small, electric aircraft that take off and land vertically (called VTOL aircraft for *Vertical Take-off and Landing*, and pronounced *vee-tol*), will enable rapid, reliable transportation between suburbs and cities and, ultimately, within cities.

The development of infrastructure to support an urban VTOL network will likely have significant cost advantages over heavy-infrastructure approaches such as roads, rail, bridges and tunnels. It has been proposed that the repurposed tops of parking garages, existing helipads, and even unused land surrounding highway interchanges could form the basis of an extensive, distributed network of "vertiports" (VTOL hubs with multiple takeoff and landing pads, as well as charging infrastructure) or single-aircraft "vertistops" (a single VTOL pad with minimal infrastructure). As costs for traditional infrastructure options continue to increase[5], the lower cost and increased flexibility provided by these new approaches may provide compelling options for cities and states around the world.

Furthermore, VTOLs do not need to follow fixed routes. Trains, buses, and cars all funnel people from A to B along a limited number of dedicated routes, exposing travelers to serious delays in the event of a single interruption. VTOLs, by contrast, can travel toward their destination independently of any specific path, making route-based congestion less prevalent.

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[1] Average one-way commute time of 27.6 minutes in SF zip code 94109, 33.0 in LA zip code 90017 (https://project.wnyc.org/commute-times-us/embed.html#12.00/37.7964/-122.4222), 35 in Sydney (https://www.allianz.com.au/car-insurance/news/the-daily-battle-metropolitan-commutes). 50 work weeks per year
[2] Time only stuck in traffic congestion (http://inrix.com/scorecard/), does not include all in-car time
[3] Times of India
[4] Cooper Center Longitudinal Study, 2012. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3360418/
[5] For example, the UK's proposed High Speed 2 railway would cost taxpayers £27B ($33B) over nine years for a single straight-line route between London and Birmingham—that's nearly $280M/mile, a projection that continues to increase. See http://www.bbc.com/news/business-36376837. This is just one example project; our point is that new technology can create options for transportation infrastructure that are far lower cost.

Recently, technology advances have made it practical to build this new class of VTOL aircraft. Over a dozen companies, with as many different design approaches, are passionately working to make VTOLs a reality. The closest equivalent technology in use today is the helicopter, but helicopters are too noisy, inefficient, polluting, and expensive for mass-scale use. VTOL aircraft will make use of electric propulsion so they have zero operational emissions[6] and will likely be quiet enough to operate in cities without disturbing the neighbors. At flying altitude, noise from advanced electric vehicles will be barely audible. Even during take-off and landing, the noise will be comparable to existing background noise. These VTOL designs will also be markedly safer than today's helicopters because VTOLs will not need to be dependent on any single part to stay airborne and will ultimately use autonomy technology to significantly reduce operator error.

We expect that daily long-distance commutes in heavily congested urban and suburban areas and routes under-served by existing infrastructure will be the first use cases for urban VTOLs. This is due to two factors. First, the amount of time and money saved increases with the trip length, so VTOLs will have greatest appeal for those traveling longer distances and durations. Second, even though building a high density of landing site infrastructure in urban cores (e.g. on rooftops and parking structures) will take some time, a small number of vertiports could absorb a large share of demand from long-distance commuters since the "last mile" ground transportation component will be small relative to the much longer commute distance.

We also believe that in the long-term, VTOLs will be an *affordable* form of daily transportation for the masses, even less expensive than owning a car. Normally, people think of flying as an expensive and infrequent form of travel, but that is largely due to the low production volume manufacturing of today's aircraft[7]. Even though small aircraft and helicopters are of similar size, weight, and complexity to a car, they cost about 20 times more[8].

Ultimately, if VTOLs can serve the on-demand urban transit case well–quiet, fast, clean, efficient, and safe–there is a path to high production volume manufacturing (at least thousands of a specific model type built per year) which will enable VTOLs to achieve a dramatically lower per-vehicle cost. The economics of manufacturing VTOLs will become more akin to automobiles than aircraft. Initially, of course, VTOL vehicles are likely to be very expensive, but because the ridesharing model amortizes the vehicle cost efficiently over paid trips, the high cost should not end up being prohibitive to *getting started*. And once the

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[6] "Operational emissions" refers to the emissions from the vehicle during operation, which is only a portion of the full life-cycle emissions. There is great value in achieving zero operational emissions: see the Vehicle: Emissions section for a deeper discussion on this topic.

[7] High-volume production of aircraft was was achieved during World War II and for a few years afterward. Also during the 1970's General Aviation sales reached ~20,000 units/year, but since the early 1980's have experienced sales of only a few thousand units per year.

[8] Not only are aircraft and helicopters dramatically more expensive than cars, but also the components going into the vehicles. The 430-horsepower Corvette LS3 6.2 liter crate complete engine has a MSRP of $7911 from GM (http://www.chevrolet.com/performance/crate-engines/ls3.html) yet is far more complex than an aircraft engine, such as the Continental IO-550C 300 hp engine which has a MSRP of $46,585 (http://www.continentalmotors.aero/Engine_Details/Stock_Engines/). See the Economics section for more details

ridesharing service commences, a positive feedback loop should ensue that ultimately reduces costs and thus prices for all users, i.e. as the total number of users increases, the utilization of the aircraft increases. Logically, this continues with the pooling of trips to achieve higher load factors, and the lower price feeds back to drive more demand. This increases the volume of aircraft required, which in turn drives manufacturing costs down. Except for the manufacturing learning curve improvements (which aren't relevant to ridesharing being applied to automobiles), this is very much the pattern exhibited during Uber's growth in ground transportation, fueled by the transition from the higher-cost UberBLACK product to the lower-cost and therefore more utilized uberX and uberPOOL products.

Market Feasibility Barriers

The vision portrayed above is ambitious, but we believe it is achievable in the coming decade if all the key actors in the VTOL ecosystem–regulators, vehicle designers, communities, cities, and network operators–collaborate effectively. The following are what we perceive as the most critical challenges to address in order to bring on-demand urban air transportation to market.

- **The Certification Process.** Before VTOLs can operate in any country, they will need to comply with regulations from aviation authorities–namely the US Federal Aviation Administration (FAA) and European Aviation Safety Agency (EASA) who regulate 50% and 30% of the world's aviation activity, respectively–charged with assuring aviation safety. VTOL aircraft are new from a certification standpoint, and progress with certification of new aircraft concepts has historically been very slow, though the process is changing in a way that could accelerate things significantly. We explore this topic in depth in the *Vehicle: Certification* section.

- **Battery Technology.** Electric propulsion has many desirable characteristics that make it the preferable propulsion choice for the VTOL aircraft contemplated in this document, and electric batteries are the obvious energy source. That said, the *specific energy* (the amount of energy per unit weight provided by the battery, which ultimately determines the gross weight of the vehicle) of batteries today is insufficient for long-range commutes. Additionally, the *charge rate* (how quickly the battery can be brought back to a nearly full charge, which determines operational idle time) of batteries today is also too slow to support high-frequency ridesharing operations. *Cycle life* (the number of charge/discharge cycles the cell can sustain before its capacity is less than 80% of the original, which determines how often the battery must be replaced) and *cost per kilowatt-hour* (which determines the overall battery cost) are also important to the economic viability of electric aircraft. We discuss the current state of the art battery developments, as well as promising (required) advances that are likely to occur in the coming several years in the *Vehicle Performance: Speed and Range* section.

- **Vehicle Efficiency.** Helicopters are the closest current-day proxy for the VTOLs discussed in this paper, but they are far too energy inefficient to be economically viable for large-scale operations. Helicopters are designed for highly flexible operations requiring vertical flight. With a more constrained use case focused on ridesharing, a more mission-optimized vehicle is possible, e.g utilizing distributed electric propulsion (DEP) technology[9]. Large efficiency improvements are possible because DEP enables *fixed-wing* VTOL aircraft that avoid the fundamental limitations of helicopter edgewise rotor flight, and wings provide lift with far greater efficiency than rotors. But no vehicle manufacturer to date has yet demonstrated a commercially viable aircraft featuring DEP, so there is real risk here. We cover this topic in the *Economics: Vehicle Efficiency/Energy Use* section.

- **Vehicle Performance and Reliability.** Saving time is a key aspect of the VTOL value proposition. In the ridesharing use case, we measure and minimize the comprehensive time elapsed between request and drop-off. This is affected by both *vehicle performance*, particularly cruise speed and take-off and landing time, and *system reliability*, which can be measured as time from request until pick-up. In this context, key problems to solve are vehicle designs for 150-200 mph cruise speeds and maximum one-minute take-offs and landings[10], as well as issues like robustness in varied weather conditions, which can otherwise ground a large percentage of a fleet in an area at arbitrary times. The *Infrastructure and Operations* section and the *Operations: Trip Reliability* and *Weather* sections address the challenges and compelling technology advances in these areas.

- **Air Traffic Control (ATC).** Urban airspace is actually open for business today, and with ATC systems exactly as they are, a VTOL service could be launched and even scaled to possibly hundreds of vehicles. São Paulo, for example, already flies hundreds of helicopters per day. Under visual flight rules (VFR), pilots can fly independent of the ATC and when necessary, they can fly under instrument flight rules (IFR) leveraging existing ATC systems. A successful, optimized on-demand urban VTOL operation, however, will necessitate a significantly higher frequency and airspace density of vehicles operating over metropolitan areas simultaneously. In order to handle this exponential increase in complexity, new ATC systems will be needed. We envision low-altitude operations being managed through a server request-like system that can deconflict the global traffic, while allowing UAVs and VTOLs to self-separate any potential local conflicts with VFR-like rules, even in inclement weather. There are promising initiatives underway, but they will play out over many years and their pace may ultimately bottleneck growth. The *Operations: Air Traffic* section expands on the issues here and summarizes current ATC initiatives.

[9] http://arc.aiaa.org/doi/abs/10.2514/6.2016-3920

[10] Our economic modeling shows that these performance numbers are necessary for feasible long distance commuteVTOL service. Shorter trip distances could utilize slower vehicles, with a penalty of having lower vehicle productivity.

- **Cost and Affordability.** As mentioned above, helicopters are the closest proxy to the VTOLs contemplated in this paper, but they are prohibitively expensive to operate as part of a large-scale transportation service. They are energy-inefficient and very expensive to maintain, and their high level of noise strongly limits use in urban areas. Demand is accordingly modest for helicopters, and this translates to low manufacturing volumes: current global civil rotorcraft production is only approximately 1,000 units per year, lacking critical economies of scale. Simpler, quieter and more operationally efficient vehicle designs are proposed which leverage digital control rather than mechanical complexity[11]. We expect that this shift can kickstart the virtuous cycle of cost and price reduction described earlier. Our *Vehicle* and *Economic Model* section goes into detail concerning the evolutionary pathway to a mass market through affordable vehicles and operations.

- **Safety.** We believe VTOL aircraft need to be safer than driving a car on a fatalities-per-passenger-mile basis. Federal Aviation Regulation (FAR) Part 135 operations (for commuter and on-demand flights[12]), on average, have twice the fatality rate of privately operated cars, but we believe this rate can be lowered for VTOL aircraft at least to one-fourth of the average Part 135 rate, making VTOLs twice as safe as driving. DEP and partial autonomy (pilot augmentation) are key pieces of the safety equation, discussed in further detail in the *Vehicle: Safety* section.

- **Aircraft Noise.** For urban air transportation to thrive, the vehicles must be acceptable to communities, and vehicle noise plays a significant role. The objective is to achieve low enough noise levels that the vehicles can effectively blend into background noise; ultimately we believe VTOLs should be one-half as loud as a medium-sized truck passing a house. That said, a more sophisticated measure of "noise" is required in order to properly characterize the impact of vehicle sound on a community. Electric propulsion will be critical for this objective, as well: it enables ultra-quiet designs, both in terms of engine noise and propulsor thrust noise. The *Vehicle: Noise* section addresses this issue.

- **Emissions.** VTOLs represent a potential new mass-scale form of urban transportation; as such, they should clearly be ecologically responsible and sustainable. When considering helicopters as the starting point, there is a substantial opportunity to reduce emissions. We consider both the *operational emissions* of the vehicle, i.e. emissions produced by the vehicle during its operation, and *lifecycle emissions*, which accounts for the entire energy lifecycle associated with the transportation method, including (in the case of electric vehicles) the production of electricity to charge VTOL batteries. Among the advantages of electric propulsion designs is that they have zero operational emissions. This leaves energy generation (which today is still largely coal,

[11]Current helicopters have a myriad of parts that are single fault flight critical components which require tight oversight on part production quality as well as frequent maintenance checks of individual components for wear and tolerance due to the harsh, high vibration operating environment.
[12] http://www.ecfr.gov/cgi-bin/text-idx?tpl=/ecfrbrowse/Title14/14cfr135_main_02.tpl

natural gas and petroleum-based[13]) with its associated emissions as the primary concern. This topic is covered in the *Vehicle: Emissions* section.

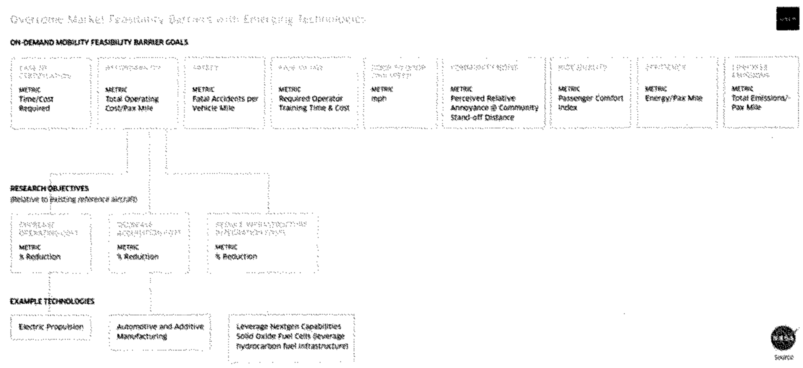
- **Vertiport/Vertistop Infrastructure in Cities.** The greatest operational barrier to deploying a VTOL fleet in cities is a lack of sufficient locations to place landing pads. Even if VTOLs were certified to fly today, cities simply don't have the necessary takeoff and landing sites for the vehicles to operate at fleet scale. A small number of cities already have multiple heliports and might have enough capacity to offer a limited initial VTOL service, provided these are in the right locations, readily accessible from street level, and have space available to add charging stations. But if VTOLs are going to achieve close to their full potential, infrastructure will need to be added. The *Infrastructure and Operations* section goes into this issue more deeply and provides the results of a simulation to determine optimal vertistop/vertiport placement.

- **Pilot Training.** Training to become a commercial pilot under FAR Part 135 is a very time-intensive proposition, requiring 500 hours of pilot-in-command experience for VFR and 1200 hours for IFR. As on-demand VTOL service scales, the need for pilots will rapidly increase, and it's likely that with these training requirements, a shortage in qualified pilots will curtail growth significantly. In theory, pilot augmentation technology will significantly reduce pilot skill requirements, and this could lead to a commensurate reduction in training time. See the *Vehicle: Pilot Training* section for more on this.

Industry Assessment of Market Feasibility Barriers

NASA and the FAA recently spearheaded a series of On-Demand Mobility (ODM) workshops to bring the VTOL ecosystem together–emerging VTOL vehicle manufacturers, federal agencies, private investors, professional societies, universities, and international aviation organizations[14]–to identify barriers to launching an on-demand VTOL service. The barriers identified by the ODM workshops group (in the below diagram) align quite well with the challenges identified in our foregoing assessment.

[13] http://www.tsp-data-portal.org/Breakdown-of-Electricity-Generation-by-Energy-Source#tspQvChart
[14] http://www.nianet.org/ODM/roadmap.htm



The remainder of this paper delves into these challenges for achieving a successful VTOL market, with an eye to surmounting them as quickly as possible, as well as our view on rider experience requirements. Our intent here is to contribute to the nascent but growing VTOL ecosystem and to start to play whatever role is most helpful to accelerate this industry's development. Rather than manufacture VTOL hardware ourselves, we instead look to collaborate with vehicle developers, regulators, city and national governments, and other community stakeholders, while bringing to the table a very fertile market of excited consumers and a clear vehicle and operations use case. At the end of the paper, we introduce an upcoming summit for vehicle developer entrepreneurs, regulators and cities, which we hope will help advance discussions and collaboration to bring on-demand urban air transportation to life.

We welcome all feedback at elevate@uber.com.

Contributors

The Uber Elevate team would like to thank all those who were involved with the writing and production of this white paper, we can be reached at elevate@uber.com.

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Dr. ALLISON. Thank you. We wanted to understand why people don't fly in cities today and what barriers must be overcome to make this possible.

In addressing these questions we identified an approach to systematically tackle each of the challenges, and in fact, our analysis not only projects aerial ridesharing as feasible but also leads us to chart a path to launch at affordable prices. Once economies of scale are achieved, we could operate at rates cheaper than owning and driving your own car.

To achieve this vision, we aim to begin testing vehicles in Texas and California by 2020 and commence certified commercial operations in 2023. During our trial phase, we intend to prove the high safety, constant reliability, and low-noise aspects of our service so we may expand passenger operations once we begin deploying certified aircraft. In both markets our service holds the promise of reducing congestion and improving quality of life.

Ultimately, no one company can do this alone. Broad-based partnerships with government and industry are critical to achieve this vision. One of our partners, Bell, is a leading rotorcraft manufacture and is well-positioned to pave the way for safe, reliable, and affordable Uber air taxis. Together with our other vehicle partners—Boeing's Aurora, Embraer, Pipistrel, and Karem Aircraft—we are actively designing new aircraft to lead a revolution in urban aviation in cities around the globe. We're proud to be collaborating with these job-creators to chart the future.

The National Aeronautics and Space Administration is another important partner. We've signed two Space Act agreements with NASA, one for the development of new UTM concepts and another to explore technologies for urban air mobility. As part of these agreements, we've completed a study on ways our aircraft will safely separate from commercial airliners in Dallas-Fort Worth airport and conducted simulations paving the way for long-term air-traffic management solutions. Additional studies to unlock urban air transportation are ongoing.

We ask Congress to encourage NASA to continue investing in this ecosystem, and we look forward to extending our collaborations with NASA and other governmental partners to work on aircraft innovation, noise limitations, and autonomous flight. As a member of the NASA Advisory Council Aeronautics Committee, I'm confident our joint research efforts can and will help open this market and ask each of you to encourage and support NASA to continue investing in this exciting new industry.

At Uber we are investing in aerial ridesharing because it has the potential to deliver time savings at affordable prices to consumers around the world. We see exceptional demand across all large markets for safe, reliable, fast transportation services, and our network can be an excellent supplement to public and private transit options across each of them.

The converging forces of improving battery technology, massive utilization through rideshare, and the advent of reliable autonomous aviation will be a true gamechanger in how people move around cities across the world. Working with visionary leaders like those at this table, we will bring about lasting positive change.

To give you a sense of how users will live this future transportation experience, I would like to close with a short video illustrating Uber Air. I hope you enjoy this projection of the future and look forward to answering your questions about our vision and our approach. Thank you.

Please play the video.

Chairman SMITH. Okay.

[Video shown.]

Dr. ALLISON. So in this video you see the integration of our service with the Uber app. The rider requests a ride and then is directed to a sky port where they're able to board an aircraft and be taken to their destination, flying above traffic. And then the vehicle goes away to take the next ride. Thank you very much.

[The prepared statement of Mr. Allison follows:]

UBER

Testimony of

Eric Allison
Head of Aviation Programs
Uber Technologies, Inc.

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

Urban Air Mobility – Are Flying Cars Ready for Take-Off?

July 24, 2018

Mr. Chairman, Ranking Member Johnson, and Members of the Committee, it is a privilege to be here before you today to discuss the role Uber will play in delivering aerial ridesharing services in the years ahead.

My name is Eric Allison, and I am excited to lead Uber's Elevate initiative. Elevate is building our future uberAIR product that aims to allow anyone to push a button and get a flight; to achieve this, we are developing a real-time, on-demand network of air vehicles to deliver time savings to riders on a massive scale.

We are developing uberAIR because we believe aerial ridesharing has the potential to radically improve urban mobility. Every year, millions of hours are wasted in traffic on roads worldwide. In 2016, the Texas Department of Transportation estimated drivers in five of the state's largest metropolitan areas lose about 52 hours a year due to congestion. And the *Los Angeles Times* reports L.A., one of our pilot markets, is the most congested city in the world. For them and for the rest of us, moments stuck on the road represent less time with family, fewer hours growing our economies, and more money spent polluting our world.

As a multi-modal transportation company, Uber believes solving this problem is core to our mission of making transportation safe, reliable, and affordable to everyone, everywhere. Just as skyscrapers allowed cities to use limited land more efficiently, urban air transportation will use three-dimensional airspace to alleviate transportation congestion on the ground. We started this journey two years ago, publishing our *Elevate White Paper*[1] to answer the questions: why don't people fly in cities today, and what barriers must be overcome.

In addressing these question, we identified an approach to systematically tackle each of these challenges. And in fact, our analysis not only projects aerial ridesharing as feasible, but also

[1] Uber Elevate: Fast-Forwarding to a Future of On-Demand Urban Air Transportation: https://www.uber.com/elevate.pdf

leads us to chart a path to launch at affordable prices, and, once at scale, to operate at rates that may be cheaper than owning and driving your own car.

To achieve this vision, we aim to begin testing vehicles in Texas and California by 2020 and commence certified commercial operations in 2023. During our trial phase, we intend to prove the high safety, constant reliability, and low noise aspects of our service so we may expand passenger operations once we begin deploying certified aircraft in 2023. In both markets, our service holds the promise of reducing congestion and improving quality of life.

Ultimately, no one company can do this alone. Broad-based partnerships with government and industry are critical to achieve this vision. Our partner, Bell, is a leading rotorcraft manufacturer and on the panel with us today. Bell is perfectly positioned to pave the way for safe, reliable, and affordable Uber air taxis. Together with our other vehicle partners — Boeing's Aurora, Embraer, Pipistrel, and Karem Aircraft — we are actively designing new aircraft to lead a revolution in urban aviation in cities around the globe. We're proud to be collaborating with these job creators to chart the future.

The National Aeronautics and Space Administration is another important partner. We have signed two Space Act Agreements with NASA, one for the development of new Unmanned Traffic Management concepts and Unmanned Aerial Systems and another to explore concepts and technologies for Urban Air Mobility. We've also completed a study on ways our aircraft will safely separate from commercial airliners in Dallas-Fort Worth Airport and conducted simulations paving the way for long-term air traffic management solutions. Additional studies to unlock urban air transportation are ongoing.

We ask Congress to encourage NASA to continue investing in this ecosystem, and we look forward to extending our collaborations with NASA and other governmental partners to work on aircraft innovation, noise limitations, and autonomous flight. As a member of NASA's Advisory Council Aeronautics Committee, I am confident our joint research efforts can and will help open this market, and ask each of you to encourage and support NASA to continue investing in this exciting new industry.

At Uber, we are investing in aerial ridesharing because it has the potential to deliver time savings at affordable prices to consumers across the world. We see exceptional demand across all large markets for safe, reliable, fast transportation services, and our network can be an excellent supplement to public and private transit options across each of them. The converging forces of improving battery technology, massive utilization through rideshare, and the outset of reliable autonomous aviation will be a true game changer in how people move around cities across the world. Working with world class leaders like those at this table, we believe we can make a sizable impact on this challenge, bringing about lasting positive change for the world in the process.

To give you a sense of how users will live this future transportation experience, I would like to close with a short video illustrating our future concept. I hope you enjoy this projection of the future, and look forward to answering your questions about our vision and approach. Thank you.

* * *

Eric Allison Bio

Eric Allison
Head of Aviation, Uber
Eric Allison is the Head of Aviation Programs at Uber. Previously, Eric spent eight years at Zee Aero leading the development of the Cora vehicle, a two-place self-piloted air taxi. He was part of the founding team at Zee, and served as CEO from 2015 to 2018. Eric received his B.S. in mechanical engineering from Milwaukee School of Engineering and his M.S. and Ph.D. from the Department of Aeronautics and Astronautics at Stanford University, studying under a Stanford Graduate Fellowship. Eric lives with his wife and young daughter in Mountain View, CA and enjoys hiking and re-discovering the area through the eyes of his child.

Chairman SMITH. Closer than you think. Thank you, Dr. Allison. Mr. Thacker?

TESTIMONY OF MR. MICHAEL THACKER, EXECUTIVE VICE PRESIDENT, TECHNOLOGY AND INNOVATION, BELL

Mr. THACKER. Chairman Smith, Ranking Member Johnson, Members of the Committee, thank you for inviting me to testify this morning on the subject of urban air mobility. My name is Michael Thacker, and I am Executive Vice President of Technology and Innovation at Bell. Made up of 7,200 employees, Bell is based in Fort Worth, Texas. My written testimony has been submitted for the record, but I appreciate the opportunity to highlight a few key elements for the consideration of the Committee.

To help set the stage, I would also like to start by sharing a video.

[Video shown.]

Mr. THACKER. At Bell, we have a legacy of leading innovation in aviation, as I mentioned, from the first American jet fighter to the first tiltrotor. Today, we are carrying that forward by creating new opportunities in urban air transportation with electric and hybrid vertical takeoff and landing aircraft.

Much work remains to be done by Bell and our partners and government agencies to operationalize on-demand mobility in the vertical dimension and bring the benefits of aviation to our communities in a way that is safe, quiet, convenient, and affordable.

Work is progressing on many fronts with our partners, including private entities like Uber and public agencies like the FAA and NASA. At Bell, we are using four integrated frameworks to help define the urban air mobility model: operational, regulatory, manufacturing, and technology. The operational framework allows us to define the necessary requirements for urban on-demand mobility. These include operational infrastructure, safety and acoustic considerations, and the critical need for a solution that is affordable for most people. The operational framework also includes local community engagement.

Bell's top priority within the regulatory framework is working with the FAA and other regulatory stakeholders to establish an integrated approach across vehicle, operational, and air-traffic requirements. We firmly believe that current aviation safety expectations should be met and even exceeded, but new vehicles and operational models may mitigate risks in new ways.

The recent modification to the certification requirements for small aircraft known as part 23, amendment 64, and its performance-based approach provides a reasonable starting point for certifying these new aircraft. We would like to see a similar performance-based approach to the integrated safety system requirements for the vehicle operations and airspace together. A holistic regulatory approach will help provide a clear path to compliance and permission to operate for urban mobility concepts.

The manufacturing framework is developing fabrication and assembly processes and technologies critical for success of urban mobility. Quality and safety are baseline expectations, so the primary efforts here focus on cost, weight, and environmental impact.

The technology framework is informed by the needs created in the other three. Bell and our partners are developing technologies such as electric and hybrid electric distributed propulsion, augmented and autonomous flight controls, and secure remote monitoring and fleet management solutions to form the basis for a new breed of aircraft and the backbone of urban mobility operations. Taken together, these frameworks will inform the continued development of Bell on-demand air mobility concepts. While we are not ready to share our program timelines, we believe viable commercial operations are possible in the mid-2020s.

The traffic congestion challenges facing our population centers aren't going away and are not likely to be solved through conventional means. We must approach tomorrow's challenges with innovative thinking that not only helps manage known issues like traffic but also creates new opportunities for technological advancement, for new career fields, for noise and pollution reduction, and for an increased quality of life for our citizens.

There is still a lot of work to be done to create a viable flight-based urban air mobility network, but we believe that future is real and coming soon to a neighborhood near you. We look forward to working with you to bring it to life.

Thank you again for the opportunity to testify, and I look forward to answering your questions.

[The prepared statement of Mr. Thacker follows:]

Urban Air Mobility: The Way Forward

Testimony of: Mr. Michael Thacker, Executive Vice President, Technology and Innovation at Bell

Chairman Smith, Ranking Member Johnson, Members of the Committee,

Thank you for inviting me to testify this morning on the subject of Air Taxis and urban mobility challenges.

My name is Michael Thacker, and I am Executive Vice President of Technology and Innovation at Bell. Made up of 7,200 employees, Bell is based in Fort Worth, Texas with facilities in Amarillo, Canada and offices and partners around the globe. Bell is part of **TEXTRON INC,** a $13.8 billion multi-industry company with 36,000 employees.

The future of our nation, and particularly our cities, rests on the ability to expand our footprint in terms of transportation, connectivity, and ease of movement. Today, I will provide an overview of what we at Bell are doing in this regard, raising issues, questions, and arguments for consideration by this body.

At Bell, innovation is in our DNA. Since 1935, we have shaped the history of aviation and delivered more than 35,000 aircraft to customers around the world, including the first fighter aircraft with tricycle landing gear, the first American jet fighter, the first aircraft to break the sound barrier, the first commercial helicopter, and the first tiltrotor aircraft.

As proud as we are of this legacy, we are equally proud of the technology and innovation advancements currently making up half of our business. Today, advances in processing power, flight controls, electric energy storage and electric motors, to name a few, are informing a new breed of aircraft concepts. Concepts that share the tiltrotor's benefits of vertical take-off and landing (VTOL) and high-speed flight, but also concepts that use much simpler propulsion systems, making them affordable enough for large-scale commercial adoption.

The convergence of these technologies is accelerating our ability to achieve real improvements in air mobility and opening new possibilities for flight, such as addressing the issues surrounding transportation congestion in urban areas. Since the first skyscraper was built, cities have been destined to become multi-dimensional, yet we still think, plan and build in a two-dimensional world, limited to places our feet can touch. We've dreamed of flying cars for decades, but until very recently, they've remained flights of fancy. With the rapid pace of technological advancement, however, small, urban aircraft may well play a role where the current solution set has failed to keep up with our needs.

We believe the real solutions to the future of Urban Mobility lie not in the two-dimensional world of roads, buses, and other traditional options, but in new frameworks and partnerships based on multi-faceted ways of thinking about the possibilities. Bell is excited to press forward into these new fronts recognizing the myriad challenges inherent in the journey, including the future of air transportation within our urban areas.

First and foremost, we need to break free of two-dimensional thinking. Space at ground level is limited, constrained by existing buildings and infrastructure. Space below ground is even more so. New, efficient ground transportation solutions still require miles of physical infrastructure to support their operation.

Around the world, tentative steps are being taken into the vertical dimension. Helicopter charter flights in New York City. Commuter gondolas in La Paz, Bolivia and Ankara, Turkey. In Tel Aviv, SkyTran is building a test loop for an elevated maglev personal transit system that, if successful, could be built at one-tenth the cost-per-mile of light rail.

"The only way to get around traffic is to literally go above it," says SkyTran CEO Jerry Sanders.

At Bell, we couldn't agree more.

Our Vision of Urban Mobility

We are actively exploring opportunities for air transportation with electric and hybrid VTOL aircraft, including urban air operations. The concept of an "Air Taxi" is nothing new; we have been moving people over urban obstacles for decades with traditional rotorcraft. What is new is the emergence and development of technologies that enable safe, quiet, efficient, affordable urban air operations at scale, using small, heavily automated electric and hybrid vertical lift aircraft.

Our vision of Urban Mobility complements and extends a broader, multi-modal transportation ecosystem. Rather than focusing on just the VTOL aircraft themselves, it is important to first define the operational requirements they must meet, as well as the transportation network they will operate within.

Defining and developing Urban Mobility solutions is a complex undertaking, requiring coordination and collaboration across industries, regulatory agencies and other communities of interest. Establishing broad agreement on the requirements, standards and regulations of Urban Mobility will accelerate the path to unlocking the benefits of aviation for all of us and, ultimately, the reshaping of our urban environments.

To realize this vision, Bell sees four areas of focus:

Physical infrastructure

The foundation of this solution is a network of vertiports, designated take-off and landing areas where aircraft will pick up and drop off passengers or cargo. These vertiports act as nodes in the network, and can be built on top of buildings and parking structures, limiting the need for ground-level real-estate. Unlike ground-based or ground-tethered transportation options, vertiports will not require miles of physical infrastructure. This makes them highly cost-effective to deploy and allows for substantial freedom in expanding and optimizing the air mobility network without disrupting and displacing existing ground-based activities.

On-demand transportation

VTOL aircraft will travel, on-demand, from vertiport to vertiport, providing fast, quiet, comfortable transportation over crowded urban landscapes. A model informed by current ride-sharing systems will help ensure availability and convenience, while making ridership cost-effective for all. We are currently partnering with groups like Uber who will help define, develop and pilot these on-demand mobility (ODM) operating models. Similar operating models will also augment existing package logistics systems.

Flight control systems

Aircraft will use predetermined flight paths to travel from vertiport to vertiport. Along the way, autonomous flight control systems will engage with each other to manage traffic flow, avoid collisions, and ensure safe, secure, efficient flights. This will require seamless operation between aircraft flight control systems and airspace control software. Existing airspace system infrastructure, along with developing systems, like those in design by NASA in partnership with the FAA, should develop ensure the needs and considerations of urban air mobility are represented to allow for the future of this ecosystem.

Aircraft technology and design

On-demand mobility will require new breeds of aircraft, employing new technologies to fulfill the mission. These aircraft will need to be lightweight, cost-effective, and employ simple, reliable propulsion systems. Because they are intended for use in urban environments, where air quality and noise pollution are important considerations, they will employ electric or hybrid distributed propulsion systems and new, quiet proprotor solutions. Aircraft will continue to evolve in design over time, and regulations must evolve to enable innovation in the service of community needs without sacrificing safety expectations.

Urban Mobility and the Air Taxi

Bell has a strong legacy of breaking new ground in aviation, from America's first jet fighter, the P-59 Airacomet, to the first supersonic aircraft, the legendary Bell X-1, and the first tiltrotor aircraft, the XV-15 and V-22 Osprey. Each required the development of new technology and new approaches to previously unknown obstacles.

The challenge we face today is developing a new breed of distributed propulsion aircraft that target the same benefits as a tiltrotor – namely the combination of VTOL (vertical takeoff and landing) capability and high-speed flight – but that employ much simpler propulsion systems and an imperative to make them affordable enough for large scale commercial use.

As we create new aircraft and concepts of operation, Bell is focusing on our customer communities, to develop solutions that enable air mobility to be more than a simple movement from point A to point B, but rather an opportunity to move across societal barriers, bringing us closer together through safer, more universal access to flight.

Part of our role is to invest in technologies and products to implement this vision of the future. Along the way, we must engage with communities of interest to ensure both acceptance and real benefit. As one of the organizations with the most experience bringing these complex systems to market, we are uniquely positioned to ensure safety, practicality and marketability.

To overcome key gaps in the current system, Bell is advancing across four integrated frameworks – operational, regulatory, technology and manufacturing.

Operational Framework

While it is tempting to leap straight to all the amazing new vehicle technology, we must start with the operational framework. How will the system work? What is the mission that needs to be accomplished? What environment will we be working within?

First, we plan to be operating in urban areas, in and around a lot of people. This comes with a safety expectation that protects both passengers and people on the ground, even in failure scenarios. It will also require an affordable solution accessible by most people. This is critical to acceptance – why would people accept aircraft operating in their neighborhood if they can't take advantage of them?

Another critical component of acceptance is managing the acoustic signature of ODM aircraft. One of the greatest hindrances to vertical lift operations in cities today is noise. To succeed in urban environments, breakthrough reductions in vehicle noise generation are a must.

At Bell, we are building on a 40+ year legacy of acoustic analysis and testing. Together with NASA and the U.S. Army, we have validated open rotor acoustic testing in both traditional helicopters and transformative lift vehicles, such as the XV-15 and V-22. Now, we are focused on fully coupled advanced proprotor modeling for both external and internal noise created by on-demand mobility vehicles. We are currently testing our ODM propulsion drive system to understand this key performance parameter and ensure we achieve our 'good neighbor' acoustic goals.

Beyond the environment driving vehicle and operating requirements, there are myriad operating details to consider, including vertiport locations, charging stations, ground safety protocols, secure passenger identification and access, and more.

We also cannot ignore normal aviation operational requirements for vehicle identification, communication and separation in a potentially more constrained airspace, or standard requirements and practices for maintenance, inspections and continued airworthiness.

Most, if not all, of these operational challenges have been addressed in some form in existing aircraft operations. We obviously already operate helicopters in many urban locations today. The system gaps come due to potential increases in traffic volume, particularly in low altitude airspace, and the increasing use of automation to enhance operational safety and efficiency.

Today, there are numerous efforts underway to outline paths forward.

The FAA recently announced the teams that will proceed with the Unmanned Aerial Systems (UAS) integrated pilot program, which targets data collection to expand unmanned aircraft operations in the national airspace.

The NASA System Integration and Operationalization (SIO) program will integrate state of the art technologies into UAS to inform FAA creation of policies for operating UAS that have Communication, Navigation and Surveillance capabilities consistent with Instrument Flight Rules (IFR) operations.

NASA also has recently announced the Aeronautics Research Mission Directorate Grand Challenge, with high-level goals to demonstrate the potential safety of Urban Air Mobility and provide the opportunity for the community to learn together in relevant and realistic operational environments.

On the industry side, venues like Uber Elevate provide the opportunity to bring stakeholders from across the ecosystem together to address system-level needs. Participants from infrastructure, technology, regulatory bodies, communities, operators and aircraft OEMs have all taken part.

Regulatory Framework

There is significant overlap between all four frameworks, and the operational and regulatory frameworks are in some sense inseparable. Whatever concept of operations we have, we need a regulatory framework that allows us to take off, depart terminal areas, fly, interact with other aircraft, approach, and land.

Bell's top priority in the regulatory framework is working with regulators to establish an integrated approach across vehicle, operational, and air traffic functions. In traditional aviation, these requirements are in many respects separated. For ODM vehicles and operating concepts, we need a holistic approach to ensure we achieve the desired safety outcomes without overburdening any one aspect of the system.

Currently, the FAA, European Aviation Safety Agency (EASA), Transport Canada and other regulators are engaging in a meaningful way to help enable these new mobility concepts. EASA recently released an internal study identifying its view of the gaps for implementing ODM in Europe. The FAA is actively engaging both on existing UAS operations and on new models moving forward. At a recent FAA-EASA international safety forum, innovation, technology, autonomy and on-demand mobility operations were significant elements of the agenda.

Taken together, it is clear much of the regulatory framework for ODM vehicles and operations is already in place. The key areas of discussion moving forward will be the means of showing compliance to our high safety expectations with these new vehicles and operating models.

Manufacturing Framework

Beyond the requirements of the vehicle and operations lies production at scale. For on-demand mobility concepts to succeed, affordability and environmental targets must be achieved, and the manufacturing framework helps address these opportunities.

While the production environment also had regulatory and quality expectations, those are baseline assumptions. The focuses of development in the manufacturing framework are cost, weight and environmental impact.

We are developing numerous advanced manufacturing technologies to enable our future factory to be safe, efficient, flexible and accurate. One area of study is the application of rapid prototyping techniques to full-scale production. These include the application of augmented and virtual reality to prototype and full production design, universal component specifications to ensure precise tolerance, streamlined production and efficient field replacement, and 3D printing for rapid design iteration and efficient production for some parts. These techniques hold the potential to enable faster, more efficient production and to bring costs down, as well as the flexibility to design and produce aircraft variants for different applications using common technologies and components.

Technology Framework

The technology framework underpins and enables the others, but it also requires the guidance of the other frameworks to focus and refine efforts.

The innovations being created at Bell are the foundation for a new era of flight. The technology framework for tomorrow's on-demand mobility aircraft includes autonomy and artificial intelligence, electric or hybrid distributed propulsion, and advanced algorithms for integrated aero-acoustic, propulsive and flight controls.

These engineering challenges are being addressed aggressively, but we are at the same time mindful of the lessons we learned while creating the first operational transformative flight vehicle, the V-22. We fully expect new discoveries and new challenges to refine our efforts going forward.

Technology Framework – Man-Machine

One key technology focus area is the man-machine interface. Rapid progress in autonomy will change the way we fly, and ultimately what it means to be a pilot or aircraft operator. In reality, this change has been ongoing for many years, with the move from simple analog gauges to digital displays to today's full glass cockpits, and from mechanical flight controls to fly-by-wire and fly-by-light controls and flight control systems that intelligently manage flight and compensate for aircraft failures.

Today, safe, unmanned operations are already possible. Bell has safely and successfully deployed autonomous technology for 18 years. In many ways, autonomous aircraft are more feasible than autonomous cars, which must contend with the unpredictable variables of human-operated vehicles, pedestrians and wildlife. We fully expect to progress to autonomous flight with passenger-operators in the future.

Beyond autonomous flight, it is also critical to consider remote monitoring and fleet management. In the ODM model, individual aircraft may be fully automated, but they will need to communicate seamlessly with air traffic controllers and with other aircraft. This is an area where we are collaborating closely with partners to develop robust, secure airspace and fleet control solutions.

Technology Framework – Propulsion

Propulsion systems have been a key enabler for nearly every breakthrough in aviation. For on-demand mobility, Bell is developing or working with partners to develop both electric and hybrid-electric distributed propulsion systems.

We have recently announced our collaboration with Safran on the development of an innovative hybrid-electric propulsion system. This hybrid system will support our ODM vehicle at approximately 6,000 pounds maximum takeoff gross weight (MTOGW), with range extension opportunities 3-4 times greater than current all-electric solutions.

While our initial flight demonstration vehicle will employ hybrid-electric propulsion, Bell's engineering teams continue to work the parallel path of all-electric architectures. The limiting factors today are battery energy densities and rapid charging capability without significant life degradation.

In the future, the selection and vehicle integration of these systems will depend on technology maturity and specific operational requirements.

Technology Framework – Science and Technology Opportunities

For this committee, Bell sees numerous opportunities to make an impact on the ability of the US to lead in this emerging aviation field. There are several key technology areas common to almost all of the concepts for vehicles and operations.

Energy storage: The ability to achieve commercially viable combinations of payload and range will require energy densities beyond the current state of the art. Battery energy densities have increased dramatically over the last years, but still lag significantly behind hydrocarbon fuels. Key areas for research include new chemistries or even storage systems for improved energy density, rapid recharge capability and reduced life degradation with recharge cycles.

Electronic hardware: Communication, navigation, separation and other key system functions are driven by electronic hardware and software. Low cost, low weight, high reliability sensors and electronic hardware can help enable these power and weight sensitive vehicles while ensuring safe operation in the airspace.

High voltage electrical power distribution and control: This research area is driven by the high-power requirements for vertical takeoff and landing combined with the need for light weight and high efficiency in the generation and distribution of the electrical propulsion power.

Artificial intelligence and man-machine teaming: For the vehicle, the airspace system and for manufacturing, optimizing the use of man with machine can unlock new capabilities and efficiencies.

Beyond these basic research areas, continued support of FAA and NASA aeronautics research particularly in airspace integration of UAS and other ODM vehicles is critical to successful launch and operation of these platforms.

Extensibility of Integrated Frameworks

While the primary focus of this testimony has been on passenger carrying systems, the integrated frameworks that enable an air taxi also enable numerous other on-demand mobility applications. Autonomous, electric or hybrid electric, distributed-propulsion VTOL aircraft could serve many roles across many industries, including logistics, shipping, manufacturing, and first responder support for search and rescue, medical transport, disaster relief and more.

One vehicle concept we are actively developing is called Autonomous Pod Transport (APT). While we envision this VTOL transport aircraft as a tailsitter that rotates into level flight, a different mode of operation than our current air taxi concepts, we see many opportunities for shared technology development, including distributed propulsion systems, quiet, efficient rotor systems and autonomous flight control systems.

Furthermore, we anticipate the commercial technologies developed for ODM to have potential for our military customers as well. Bell is working with U.S. armed forces on multiple projects, and can envision numerous applications for similar technology in the field, from scouting and forward air control to maritime patrol, light personnel and cargo transport, and medevac operations. Autonomous or semi-autonomous flight reduces risk for military personnel, as do reduced acoustic signatures. Distributed propulsion systems may also offer a higher degree of redundancy and survivability compared to traditional platforms.

Concept Designs and Development Timeline

Bell has been developing air taxi concepts, along with the technology and infrastructure to enable them, for quite some time. While we are not sharing all of our designs or timelines, we believe viable commercial operations could begin as early as the mid-2020's.

Regulatory Barriers and Gaps

Bell and our partners are working aggressively to bring this set of ODM solutions to life. As we do, it is clear that the existing safety system framework encompasses all of the elements needed for these new aircraft and concepts of operation. However, the existing standards will need to be adapted, and new means of compliance will need to be accepted. Traditionally, airworthiness standards have been largely a collection of lessons learned and best practices. While that has advantages in some respects, it has left us with prescriptive rules that fit yesterday's technology better than future technology.

The on-demand mobility ecosystem will require flexibility to accommodate multiple technology and vehicle types. Numerous developments are already underway, and will continue as the needs of the audience, environment, and overall mission evolve. The path for ODM vehicles already has been helped by amendment 64 of Part 23. Bell believes Part 23 plus special conditions, either unique or from Part 27 or other existing policy and guidance material, can provide a reasonable basis for vehicle certification. At amendment 64, most of the prescriptive means of compliance were moved into consensus-based industry standards leaving the true safety objectives within the Part 23 requirements. This format provides a more adaptive framework to define and accept new means of compliance associated with different technologies and configurations. Extending the Part 23 performance-based approach to Part 25, 27 and 29 would further enhance the path to safe integration of technologies across aircraft platforms and specifically for transitional ODM vehicles.

The regulatory opportunity, however, extends beyond certification of the vehicle. For ODM operations to be success, we need an integrated solution across vehicle certification, flight standards and air traffic control. Today, safety is managed across the system with risks mitigated in each area. However, we have traditionally treated the areas as silos. With increasing automation and the unique attributes of many ODM configurations, risk mitigation and safety outcomes will be managed across the silos rather than within them. We need a holistic approach to ensuring our expected safety outcomes without inappropriately burdening the aircraft or any other individual part of the system based on assumptions that no longer apply.

In this regard, we were pleased to see FAA leadership begin to engage industry with all elements of the FAA team involved in the conversation. This is a positive step toward understanding the overall safety system for ODM and ensuring that we proceed together to define viable solutions.

In addition to aircraft and operating standards, ODM landing sites within urban airspace will require consideration for standards related to landing zone requirements, refueling, secure air fields, and related issues. Each city will have some unique needs based on zoning and the skyline profile and altitude dynamics of that location, as well as density and traffic demand, flow patterns, on-demand operators, and other aircraft in the area. ODM guidelines will need to account for the flight environment and dynamic area in which urban flight takes place, but also plan for growth and expansion into other solution areas that may have completely different needs, like industrial parks, agricultural areas, remote manufacturing, tourism, or other future solutions.

Despite these local integration needs, it is important that standards for the aircraft and for operations are common across the US and preferably across the globe. To that end, it is important that Federal preemption for the FAA in the area of aviation is respected legislatively and judicially.

Close coordination and cooperation with governments and regulatory agencies is critical for the development of appropriate regulation that provides a clear path to compliance and authorization to operate with guardrails, rather than roadblocks. Furthermore, the FAA, EASA and other regulators should work together to develop a globally coordinated safety system expectations through agreed-upon consensus standards that ensure the viability of reciprocal airworthiness acceptance. We are encouraged in this regard by recent progress, including the activity of the General Aviation Manufacturers Association Electric Propulsion Innovation Committee (GAMA EPIC), which has brought both voices to the conversation together, and we encourage both agencies to seek opportunities for continued collaboration.

When considering this space and the diversity of flight platforms in development, there are many 'correct' solutions to provide safe, efficient, effective transportation in various forms. Standards must allow for and encourage smart development and problem-solving as industries come together to address these challenges. Limiting tomorrow's solutions with yesterday's design and testing rules not only prevents creative technology, it reduces interest in the field from the greatest minds and can inhibit overall development.

The goal, ultimately, is to create a regulatory approach that allows good ideas in while at the same time ensuring safe and effective operation.

Public-private cooperation has helped establish regulatory approaches in the past. At Bell, our depth of knowledge and experience across regulations provides a strong foundation for working with regulators to define appropriate paths forward for showing compliance.

We are already engaged with the FAA and look forward to working with them to help chart the paths toward safe and compliant ODM operations.

Safety and Security

Beyond the hype and excitement, to be successful, these new systems must be safe and secure to warrant the public confidence and widespread usage. Bell expects these new systems to produce safety outcomes that are equivalent or better the today's aviation system expectations for similar aircraft. As noted above the regulatory system needs to be flexible enough to rapidly enable these new aircraft and operating concepts, but robust enough to ensure we maintain our high expectations of aviation safety.

Summary and Conclusion

Creating a real, viable Urban Mobility network isn't something that is going to happen tomorrow, but this future is closer than many people realize. Across private entities like Bell and our partners, as well as government agencies including NASA and the FAA, this future is being actively, aggressively pursued.

The Bell focus, detailed in the above testimony, is framed through four integrated frameworks that help define the Urban Mobility model, develop the enabling technologies, chart a path for regulatory support and ultimately inform aircraft design and operating requirements.

Many of America's greatest accomplishments—from the Manhattan Project to the space program to the internet—were only possible through effective public-private partnerships. The promise of another great American accomplishment, true Urban Mobility in the vertical dimension, now lies before us, and along with it the promise of carrying on America's long legacy of leadership and innovation in aviation. We are pursuing the technology that will make this dream a reality, but we need your support to help drive basic science and technology investments and to create a framework of regulation and oversight that allows for rapid and even radical innovation while ensuring safe, effective deployment and operation.

As we speak to this Committee today, all the issues we have addressed are viewed through a solutions-oriented lens. We are, after all, a solutions-oriented company, driven to find not just any answer to a given challenge, but the right answer, especially when it requires innovative thinking, breakthrough technologies, or developing entirely new classes of aircraft.

Today we are presenting the conceptual approaches we believe will work not only for a more mobile, more functional American future, but that will create more freedom and efficiency in how we work and live. Opportunities that can create a cleaner, quieter, more efficient urban environment, and advanced technology solutions that offer any number of job opportunities in our US-based facilities or with one of our many talented partners. We are committed to a stronger, more mobile future, and will do our part to bring it to life.

Thank you to Chairman Smith, Ranking Member Johnson, members of the Committee, our fellow speakers, and everyone in attendance for the opportunity to speak with you today.

MICHAEL THACKER

Executive Vice President,
Technology and Innovation – Bell

Michael Thacker was named Executive Vice President for Technology and Innovation in February 2017 and is a member of Bell's Executive Leadership Team.

In his current role, Michael is responsible for leading Bell's core engineering team and providing strategic direction for designing, developing and integrating technologies for use in Bell's current and next generation products.

Michael was previously the senior vice president of Engineering at Textron Aviation, where he was responsible for the engineering efforts of Beechcraft, Cessna and Hawker product lines. This included new aircraft development, certification, compliance, experimental fabrication, technical publications and product safety, as well as engineering product support for all aircraft in production and legacy models.

Michael joined Cessna in 1993 as an engineer in propulsion integration. Since then, he has held various positions of increasing responsibility in engineering and program management. Prior to being promoted to senior vice president in July 2011, Michael held the position of director of Research and Advanced Technology from 2008. In that role, he managed and directed new product and technology development programs and processes. His responsibilities included product and technology strategy and program initiation and execution. In addition, he led the aerodynamics function for all products and phases of maturity.

Michael holds a Bachelor of Science in Aerospace Engineering and a Master of Science from Kansas University. He also holds a MBA degree from the Fuqua School of Business at Duke University, NC.

Chairman SMITH. Okay. Thank you, Mr. Thacker.
And Ms. Dietrich?

TESTIMONY OF MS. ANNA MRACEK DIETRICH, CO-FOUNDER AND REGULATORY AFFAIRS, TERRAFUGIA

Ms. DIETRICH. Thank you, Chairman Smith, Ranking Member Johnson, and Members of the Committee. I appreciate the opportunity to be here this morning to talk to you about something that I've been working on for well over the last decade.

My name is Anna Mracek Dietrich, and I'm one of the original founders of Terrafugia. I currently lead our company's regulatory and policy efforts.

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[Slide.]

Ms. DIETRICH. Terrafugia was founded in 2006 to help address the $160 billion transportation challenge that we face in this country. Today, we're employing over 150 people across three locations in the United States and are getting ready to bring our first general aviation product, the Transition, what you see on the screen, to market next year.

Following Transition, which takes off and lands from airports and is street legal to drive home and park in your garage—we are pursuing an eVTOL concept, which we're currently calling TF–2.

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[Slide.]

Ms. DIETRICH. You can see some information about it here, but I think a video is worth more than 1,000 words if you could please go ahead with that.

[Video shown.]

Ms. DIETRICH. So the idea behind TF–2 is that it is a three-part system. It fully integrates ground and air transportation, so you are picked up by the ground vehicle with the passenger pod at your origin. It drives you to a vertiport where you're connected to an electrical vertical takeoff and landing air vehicle, which then flies you across traffic to your final destination.

Unlike some of the other entrants into this space, TF–2 has a little bit of a longer range. We are using a hybrid electric power system for flight, and that gives us a range of around 200 miles, which allows not only urban operations but could bring in people from surrounding rural areas for hospital visits, things like that as well. And then once you are on the ground, another ground vehicle picks you up and takes you to your final destination.

We're anticipating around $30 for a 10-minute flight, and that should take about 20 minutes over traffic, so it should be an accessible form of transportation.

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[Slide.]

Ms. DIETRICH. So there's three pieces of the regulatory landscape that I see as being necessary to support this new technology—Ms. Johnson mentioned several of these in her opening remarks—the airworthiness certification, operations and operators, and air-traffic control. The airworthiness certification is the most mature of all of these areas. As was mentioned, the Part 23 rewrite, which was completed last year, is a key piece of that. Having safety intent regulations really do allow additional innovation to be brought into general aviation, so that is where we anticipate certifying these aircraft is in Part 23, Amendment 64. You can see the comparison to Part 27, which is rotorcraft, and it's significantly more appealing to go into Part 23.

From the operations and operators' perspective, that's where we start talking about bringing autonomy into the equation, everything from how do we appropriately train pilots to accommodate for new technologies in the cockpit through how do we ultimately certify an aircraft to be safe to be flown without a human directing it? So that's a whole spectrum of efforts that are currently ongoing from both the operational and aircraft certification and training perspectives.

Air-traffic control, I see it as very important that we consider our airspace as unified airspace, so it's very tempting to try to segregate both along the lines of existing airspace sort of designations, but as well in terms of industries. And as you can see in the graphic there, it really is a transportation ecosystem. It's a network. Everything from small unmanned drones that might be delivering your packages all the way through commercial airliners, there's a lot of different uses for the sky, and they all need to be combined into a constructive single system.

So as we look forward to systems for that, I think there's a few pieces that we need to keep in mind. One is that we need to be thinking about incorporating new technologies into how we control airspace using vehicle-to-vehicle communications, potentially getting away from voice communications, and really looking at it as a single system.

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[Slide.]

Ms. DIETRICH. So there's also some challenges associated with bringing any new technology to market and creating a new industry. These are just a few of them. I've touched on them in more detail in the written testimony, but the four that I'll highlight are connectivity, infrastructure access, technology development, and affordability. By connectivity I mean some of what I was mentioning before, both vehicle-to-vehicle communications and vehicle to air-traffic controller or other ground-based systems. This includes continued-access GPS capabilities, 5G cell data service, and appropriate frequency band allocations for transportation.

Infrastructure access spans local, state, and federal levels. Technology development, in many ways we are already well on our way towards the technology that we need to accomplish these missions in these vehicles, but additional research will set the stage for future applications.

And then affordability is really primarily within the realm of the manufacturers, but it is of course influenced by how streamlined the certification and operation processes can be.

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Ms. DIETRICH. So with that, thank you very much for the opportunity. I look forward to answering your questions and continuing the discussion past this morning.

[The prepared statement of Ms. Dietrich follows:]

TERRAFUGIA®

Terrafugia, Inc.
Testimony for the House Committee on Science, Space, and Technology

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July 24, 2018

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Prepared for the House Committee on Science, Space, and Technology, July 24, 2018
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SUMMARY

Terrafugia was founded in 2006 to be part of the solution to the $160 Billion traffic congestion problem in the U.S. Its first product, the Transition® is a street-legal Light Sport Aircraft designed to be flown in and out of the nearly 5,200 public local airports around the country with true door-to-door transportation provided by its ability to drive like a car on roads and highways. Terrafugia has been flight testing full size Transition® aircraft since 2009 and anticipates first delivery in 2019. Following Transition®, Terrafugia is developing the TF-2 transportation system, a combination of a ground vehicle, passenger pod, and winged electric vertical takeoff and landing (eVTOL) flight vehicle. Providing a unique approach to urban and suburban transportation, TF-2 is leveraging developments in electric propulsion and vehicle control systems with a five to ten year commercialization timeline.

While Transition® is focused on the existing general aviation (GA) market, TF-2 and other eVTOL aircraft are creating a fundamentally new market referred to as urban air mobility (UAM). The key idea behind UAM is that new eVTOL aircraft can provide safe, reliable, quite, and convenient transportation by utilizing a network of vertical take-off and landing sites in and around our city centers. With a hybrid-electric propulsion system, TF-2 will have a larger range (around 200 miles) than other all-electric entrants, giving it the ability to service larger geographic areas. It's ability to seamlessly combine ground and air transportation for passengers, who don't have to leave the vehicle to from being driven to being flown, provides additional flexibility and safety as well. As electric technology continues to improve, an all-electric version is possible. A similar evolutionary approach is being taken to integrating autonomy: initially TF-2 vehicles will be driven and flown by appropriately trained and certificated drivers/pilots. As the technology and regulatory landscapes evolve, it is possible that the role of the human operators will decrease to allow the benefits (including potential increases in safety and reductions in cost) of autonomous operations to be realized.

The regulatory landscape in which TF-2 and other eVTOL aircraft are being developed is made possible by the Rulemaking, completed in 2017, that rewrote 14 CFR 23 to focus on safety intent language for general aviation (GA) aircraft airworthiness certification instead of prescriptive requirements. This shift opened a certification pathway for innovative technology that can increase the safety, utility, and desirability of traditional GA aircraft as well as for entirely new aircraft concepts like eVTOL and UAM. It is critical that the Federal Aviation Administration (FAA) continue this collaborative and innovation-focused approach in the other key areas: operations and operator training and air traffic control (ATC) and airspace access. Continuing this forward-leaning approach is critical for the success of this industry and the continued growth of the U.S. economy and technology leadership. Beyond the FAA, there are opportunities for the federal government to support this industry in addressing challenges in connectivity, infrastructure access, affordability, and technology development.

This is an exciting time in the evolution of our transportation capabilities as new technologies are being developed to bring us all closer together through the safe and innovative use of on demand personal air travel.

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1 INTRODUCTION

Chairman Smith, Ranking Member Johnson and Members of the Committee, I appreciate the opportunity to appear before you today to discuss the topic of urban air mobility and its potential applications in our nation's transportation system. My name is Anna Mracek Dietrich, I am one of the original founders of Terrafugia and I lead our company's regulatory efforts with the federal government.

2 BACKGROUND

Highway traffic congestion has increased for the past three decades in all urban areas, costing the U.S. $160 Billion in 2014[1]. Meanwhile, the nation's general aviation airport infrastructure remains largely underutilized. The main reasons that personal aviation has not been a significant solution to transportation include significant training requirements, high cost of ownership, long door-to-door travel time, weather sensitivity, and lack of mobility at the destination airport[2]. An innovative combination of driving and flying in the same vehicle or transportation system, particularly in an on-demand or frequently scheduled operational model, coupled with reduced or eliminated pilot training requirements, address all of these barriers and has the potential to be a contributor to the solution to traffic congestion.

Terrafugia, Inc. is an MIT spin-off company that was incorporated in 2006 with the goal of increasing the practicality, convenience, fun – and of course safety – of personal aviation through just such an innovative combination of ground and air travel. Terrafugia's first product, the Transition® is a Light Sport Aircraft that carries a Sport Pilot[3] and passenger between any of the nearly 5,200 public use airports around the United States. Once on the ground, the wings can be folded with the push of a button and the street-legal vehicle can be driven home and parked in the owner's garage, or to their final destination. Terrafugia has been flying full-size Transition® prototypes since 2009 and is targeting deliveries in 2019. See Figure 1.

Over the course of developing the Transition®, Terrafugia has gained valuable experience working with both the Federal Aviation Administration (FAA) airworthiness requirements and the Federal Motor Vehicle Safety Standards (FMVSS) and applying them to innovative and new aircraft. Terrafugia has received two exemptions from the FAA and four from parts of the FMVSS where the requirements were either not appropriate for a vehicle like the Transition® or where they didn't contemplate the safety needs of a vehicle that could both fly and drive. Terrafugia has also been a leading participant in industry efforts to modernize the certification landscape for general aviation (GA) aircraft.

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[1] Transportation Statistics Annual Report 2017, U.S. Department of Transportation, Bureau of Transportation Statistics (available at: https://www.bts.gov/bts-publications/transportation-statistics-annual-reports/tsar-2017)
[2] Downen, T. and Hansman, Jr., R. J., "User Survey of Barriers to the Utility of General Aviation", Massachusetts Institute of Technology, 2002-01-1509.
[3] The FAA's Light Sport Aircraft and Sport Pilot Rule in 2004 reduced the barriers to entry for both aircraft that meet certain requirements and for the pilots that fly them.

In that role, I served on the Federal Aviation Administration's Aviation Rulemaking Committee (ARC) that recently rewrote 14CFR23 and hold leadership positions on the ASTM industry consensus standards committees that are responsible for both Light Sport and General Aviation Aircraft (F37 and F44, respectively), including serving as the Vice Chair for F44. Additionally, I am leading the ASTM effort to create a standards framework for autonomous and complex aircraft systems under ASTM AC377.

The changes to the regulatory landscape are particularly important for Terrafugia's future products, which include an electric vertical take-off and landing (eVTOL) modular transportation system (discussed further in Section 4). This future product development and dramatic company growth has been facilitated by an infusion of capital that began with its acquisition in late 2017. Now a sister company of Volvo Car Group and other international automotive brands under Zhejiang Geely Holding Group, Terrafugia has access to the capital necessary to both take Transition® to production and to develop the next generation of innovative personal aviation solutions. The 2017 deal received approval from all relevant regulators, including the Committee on Foreign Investment in the United States (CFIUS), and has enabled Terrafugia to not only survive in the absence of willing U.S.-based capital but to grow from one location with around twenty employees to three U.S. facilities with nearly two hundred employees. This growth is continuing at Terrafugia's headquarters in Woburn, MA, a flight support center in Nashua, NH, and its Research and Development facility in Petaluma, CA.

3 What is Urban Air Mobility and eVTOL?

Urban Air Mobility (UAM) is, broadly, the idea that aviation can be used to address transportation challenges and congestion within an urban environment. While previously efforts have been made to accomplish this goal using helicopters, a combination of factors including safety concerns and noise prevented helicopter-based UAM from gaining a lasting foothold in the US. Other markets, like Sao Paulo, Brazil, have seen modest success with helicopter-based UAM solutions, but they cannot approach the volume of flight operations that are envisioned for eVTOL-based UAM, in part because of air traffic control (ATC) limitations, or the expected noise and safety targets enabled by emerging technology. The UAM construct requires that there be aircraft that can operate safely, quietly, reliably, economically, and in an environmentally friendly way near, around, and within our urban centers.

Urban Air Mobility is a subset of a broader transportation concept known as on demand mobility (ODM). ODM can be applied to any mode of transportation so long as the user can get the transportation they need when they need it. It is an alternative to the private ownership model that requires an individual to provide the capital to purchase a vehicle and be directly responsible for its operational, storage, and maintenance costs whereby the user simply pays for the transportation-as-a-service that they receive. Particularly for aircraft, this is appealing as it defrays their high purchase price and maintenance expenses over a much larger utilization fraction and multiple users, creating a more economical solution.

Electric Vertical Takeoff and Landing (eVTOL) refers to aircraft that use electric motors to provide the ability to take off and land vertically, without a traditional runway, utilizing existing heliport or other purpose-built vertiport infrastructure. This technology provides an opportunity to realize the goals of UAM. By leveraging the increased safety and reliability of electric motors while taking maximum advantage of their extremely low noise profile and reduced operational costs, eVTOL aircraft can provide an economically viable means by which many urban and suburban residents could incorporate aviation as a solution to their routine transportation needs. Aircraft that use wing-borne flight to travel between take-off and landing locations as well as those which rely solely on powered lift are both included in the eVTOL umbrella, as are aircraft that use a hybrid propulsion system with a conventionally-fueled engine to recharge the batteries and/or provide en route propulsive power.

4 TERRAFUGIA'S APPROACH TO EVTOL

Terrafugia is currently working on conceptual design and subscale prototyping of an eVTOL transportation solution, the TF-2. A door-to-door three part transportation solution, TF-2 consists of a passenger (or cargo) pod that is connected to a ground vehicle for road use and a flight vehicle for winged eVTOL use. This allows for a seamless door-to-door experience for passengers, and can accommodate what could be a potentially slow roll-out of available landing sites within urban centers. See Figure 2 and Figure 3 for a schematic of the door-to-door operational concept and the three pieces of the vehicle system. Figure 4 depicts a possible solution to landing infrastructure with a TF-2 flight vehicle landing on a barge adjacent to a city center.

It is expected that the TF-2 flight vehicle will have a payload of approximately 1,000 lb, fly around 125 mph, and have a range of around 200 miles (while maintaining the current minimum reserve requirements). The anticipated cost for a ten minute flight is about $30 per person – during which time the user could be transported 15 to 20 miles – above the traffic.

TF-2 improves the operational safety and efficiency of vertical flight by keeping untrained people off of the landing pad (they will be seated in the pod during the loading/unloading process) – this will allow faster, safer operations while simultaneously improving the end-user experience because they do not need to get out of the pod until they are at their final destination.

TF-2 is being designed to accommodate expected rapid evolution in both technology and the regulatory and operational landscape. With a hybrid-electric flight vehicle, TF-2 can achieve a range sufficient to allow cross-city flights, such as from Santa Rosa in the north to San Jose in the south over the heart of the San Francisco Bay Area (about 100 miles) or at the outside of its range from the Boston, MA metro area to the New York, NY metro area (about 200 miles), as well as more local trips such as from San Jose, CA into downtown San Francisco[4], or shorter. This range would also allow underserved rural communities to have efficient access to regional airport infrastructure, hospitals, or other urban services. Electric motors provide the necessary low-noise operations and safety for vertical takeoff and landing while a conventional certified turbine engine provides cruise power and the ability to recharge the batteries in flight. As battery technology continues to evolve, it is conceivable that an all-electric version could be produced in which the engine and fuel tanks are replaced with additional batteries.

[4] These trips are provided for illustrative purposes only. Terrafugia has not committed to a geographic launch area at this time, though it is likely that testing will continue to be conducted near the company's facilities in the San Francisco Bay Area and in New England.

The ability of the passenger pod to be driven to a final destination means that if there is initial local resistance to landing these aircraft in city centers, or delay in expanding on the existing landing site infrastructure, significant benefit can still be obtained from their use. A human driver is anticipated and accommodated in the ground vehicle, but if autonomous driving capability (and the associated regulation) matures to the point where it would make sense to deploy an all-autonomous ground vehicle, necessary sensors and software will already be in place to make the shift safely and expeditiously.

Likewise, a commercial fixed-wing pilot will be operating the flight vehicle, at least initially, with the assistance of vehicle systems and software that enhance safety and simplify vehicle controls. Such systems include ground collision avoidance and automatically guiding the aircraft through the transition from vertical to horizontal flight, a maneuver which has traditionally proven difficult for human pilots to master. As progress in technology development, certification, and operational constructs with Simplified Vehicle Operations (SVO) and autonomy in aircraft advances, it will be possible to revisit this piece of the operations. Safely reducing the training required for a flight vehicle operator and/or ultimately removing that role may be necessary as adoption of UAM vehicles may outstrip the ability to train commercial pilots – a capacity that is already strained by the airline industry. Ultimately, safety may also be increased by moving to autonomous operations as 58% of fatal general aviation accidents are caused by either controlled flight into terrain or loss of control – both pilot errors and the top two causes of fatal accidents[5]. Data collected during piloted operations will facilitate this evolution.

These incremental approaches to technology implementation in the TF-2 system allow Terrafugia to bring a product to market without waiting for an undetermined, and difficult to control, technology and certification methodology development timeline. While it is still early in the development process, TF-2 is expected to be in commercial use in five to ten years. Production is anticipated to be in the low thousands of units annually.

5 Regulatory and Operational Landscape

There are three main pieces of the regulatory and operational landscape that need to be in place in order for eVTOL aircraft like TF-2 to be put into commercial UAM/ODM service: aircraft airworthiness certification, operations and operator training/certification, and air traffic control. Of these three, the aircraft airworthiness certification solution is the most mature.

In 2004 the FAA formally began working with industry consensus standards for aircraft certification with the Light Sport Aircraft Rule that uses standards developed by ASTM Committee F37. Building on the success of this new category and certification approach, an Aviation Rulemaking Committee (ARC) was launched in 2007 with participation from both industry and the FAA. The task of this ARC was to review and revise 14CFR23 Airworthiness Standards: Normal Category Airplanes, which cover general aviation aircraft up to 12,500 pounds and 19 passengers and are referred to in the industry as "Part 23". Over time, Part 23 had evolved to contain detailed prescriptive requirements that drove very specific

[5] The General Aviation Joint Steering Committee Pareto Chart, 2008 (available here: http://www.gajsc.org/gajsc-pareto/)

engineering solutions, creating an environment that was not conducive to innovation and could not easily accommodate new technology in aviation, regardless of its potential safety benefit. The result of the efforts of the ARC is 14CFR23 Amendment 64, which was formally made available for use in August 2017[6].

Part 23 Amdt 64 is dramatically shorter than its predecessor with about a third of the number of requirements. These requirements are also written to be based on a "safety intent", in other words, to answer the question of what is it that makes a safe airplane, instead of to tell the manufacturer what exactly they have to do from an engineering perspective. This dramatically increases the flexibility of Part 23 to accommodate new vehicle configurations, technologies, and innovations that increase the safety and utility of general aviation. In order to not lose the knowledge and experience that had been captured in the previous version of Part 23, those prescriptive requirements were moved to the jurisdiction of an ASTM industry consensus committee (F44 General Aviation) that was initiated for the task of creating and maintaining a body of standards that could be used as an Accepted Means of Compliance for Part 23[7]. Those standards can be – and are – revised and created in response to new technological developments on a much shorter timeframe, 6 months to a few years is typical, than a Rulemaking. It is expected that eVTOL aircraft like TF-2 will be certified using Part 23 Amdt 64 and a significant number of the accepted ASTM standards. While work is ongoing and full Agency alignment has not yet been achieved, a clear and constructive airworthiness certification path is available for these aircraft.

Operations and Operator training and certification is particularly interesting for eVTOL aircraft because of the unique nature of on-demand mobility, the large number of anticipated operations/aircraft, and the safety-enhancing and enabling role of autonomous and complex systems in the aircraft themselves. From an operational perspective, 14 CFR Part 135 Operating Requirements: Commuter and On-Demand Operations and Rules Governing Persons on Board Such Aircraft is appropriate for these vehicles[8]. A detailed review of these Rules with simplified vehicle operations, autonomy, and other new technologies and operational constructs in mind is in its early stages. Some of the key questions that will need to be answered jointly between FAA and industry are how to mix traditional GA operations with the ODM model, and how to provide a certification framework for simplified, autonomous, and/or complex systems that allows their maximum safety benefit to be realized as either independent systems or in concert with a human operator or pilot.

Additionally, in the future, human operators and/or pilots will need to be trained and certificated under an updated version of the Airman Certification Standards now currently in use under 14 CFR Part 61 Certification: Pilots, Flight Instructors, and Ground Instructors that accounts for the increasing role of automation, autonomy, and other complex vehicle systems in aircraft operations. One possible way of approaching this change is to look at the required functional capabilities for the combination of the

[6] The final rulemaking notice was published on December 30, 2016 with an effective date of August 30, 2017 and is available through Document Citation 81 FR 96572.
[7] The first set of ASTM standards were accepted by the FAA on May 11, 2018. Document Citation 83 FR 21850.
[8] Transition® and other owner-operated GA aircraft fall under 14 CFR Part 91 General Operating and Flight Rules.

aircraft and pilot and accommodate a variety of ways of accomplishing and demonstrating the ability to safely accomplish those functions across a spectrum of human and machine control.

Air traffic control (ATC) and integration of new technology and vehicles into our National Airspace (NAS) is the third major component of the regulatory and operational landscape for eVTOL UAM aircraft. When thinking about the NAS, it is tempting to think about it as a segregated set of distinct operational areas both in terms of the airspace designations themselves[9] and in terms of the different users of that space, particularly small unmanned aircraft systems (sUAS), general aviation, and commercial airlines. While this strict segregation can be a useful tool for human controllers tasked with centrally controlling a large number of aircraft operations, it doesn't take into account the reality of how we need to be able to use the sky over our urban areas nor does it take advantage of the significant advances in technology that have been achieved since this structure was put into place.

For the U.S. to have a healthy aviation industry in the future, all types of aircraft, from sUAS through GA and commercial airlines, need to have an integrated, federally controlled airspace. This ATC construct will need to incorporate distributed aircraft-to-aircraft communication and move away from serialized central voice control in favor of higher bandwidth modern digital technology. Human controllers will still have a key role in this new paradigm, but it will likely be one that is more strategic and less tactical. It is also possible that the number of controllers needed may even increase despite incorporating new technology as the number of aircraft in the NAS – driven by sUAS and UAM aircraft – will increase by orders of magnitude over what exists today.

Updating the regulatory and operational landscape to accommodate eVTOL aircraft, UAM and ODM operations, and the increasing autonomy in the cockpit will not only benefit the existing and emerging facets of the aviation industry, but will set the stage for continued innovation and technological development. While the Part 23 ARC is an example of highly constructive FAA and industry collaboration, this type of future-looking effort needs to be applied across operational- and ATC-related issues as well. Lastly, in addition, it is important that the FAA collaborate and continue to harmonize its requirements with its international counterparts such as the European Aviation Safety Administration (EASA) so that products designed and built in and for the U.S. market can have streamlined international market access as well.

6 GOVERNMENT AND REGULATOR INVOLVEMENT

The autonomous automotive industry provides a cautionary example for what can happen when technology gets ahead of federal regulations. Since 2012, at least 41 states and the District of Columbia have considered legislation related to autonomous vehicles[10]. A similar fragmentation is happening now with oversight of sUAS being handled at a local level. While this localized approach can appear to be in the best interest of safety, it is not in the overall best interest of either the industry or the travelling

[9] See 14 CFR Part 71 Designation of Class A, B, C, D, and E Airspace Areas
[10] From the National Conference of State Legislatures Autonomous Vehicles report, published June 25, 2018. (available at: http://www.ncsl.org/research/transportation/autonomous-vehicles-self-driving-vehicles-enacted-legislation.aspx)

public. Without a central, federally-led regulatory and certification framework, manufacturers are left to sort through potentially conflicting requirements throughout the U.S., experts that could contribute the best perspective and create requirements that would obtain the highest level of safety are not centrally coordinated in one effort, safety-related lessons that may be learned in one jurisdiction are not efficiently propagated throughout the country, and operations that cross state lines – even more likely with aviation than with automobiles – can become overly complicated. All of this is to the detriment of safety, innovation, and economic progress. The FAA has an impressive record of providing federal leadership in manned aviation; to see this role diminished or its federal preeminence abdicated in any way would be a loss for the U.S. aviation industry and the travelling public.

As part of maintaining its regulatory leadership role, the FAA needs to continue to engage with industry in the same collaborative and open-minded fashion that contributed to the success of the Part 23 ARC. While the Part 23 ARC laid a crucial foundation for the airworthiness certification of eVTOL aircraft, the Agency must continue to build on that foundation by implementing certification programs with industry that meet the scheduling, safety, and international acceptance needs of the eVTOL aircraft programs. Beyond Airworthiness Certification, the Flight Standards and Air Traffic Control functions of the FAA need to fully engage with industry in a manner that will allow these pieces of the puzzle to be advanced in a constructive and timely manner. If it is determined as part of this process that additional Rulemaking activities are needed to support this industry (and it is likely that this will be the case), it is crucial that the government allow these efforts to progress at a pace that can keep step with the high levels of investment and progress that are being demonstrated by industry in this area. It is notable that this is an area where new federal regulation is likely to be a welcome enabling piece of creating a responsible and growing new industry, not a hindrance.

Beyond regulation and certification, the government has a valuable role to play with its funding of research through both NASA and the FAA. While NASA is often seen as exclusively focused on space exploration, the reality is that its aviation-related functions are also quite valuable. With research in electric aircraft and low-speed flight characteristics, NASA is in a position to be a major contributor to the ASTM Means of Compliance efforts for eVTOL aircraft. Their work into UAS-related ATC issues (referred to as UAS Traffic Management, or UTM) also has value as it relates to creating a new paradigm for integrated use of our national airspace. While the technology transfer timeline means that it is unlikely that any new hardware research funded today would make its way into the first generation of eVTOL aircraft, continued involvement in Standards generation is highly valuable in the short term. Taking a longer term view, future-looking aviation research today may help create the next revolution in aviation tomorrow so should not be discounted due to a perceived lack of short-term gains.

7 ADDRESSING CHALLENGES

While the future is bright for personal aviation, challenges of course remain. Together, industry and government at all levels will need to ensure that in addition to the regulatory and operational challenges discussed in Section 5 the following are addressed appropriately.

Connectivity: This is a cross-functional challenge in that it encompasses both the need for communication infrastructure (e.g., continued GPS availability, 5G cell data service, and appropriate frequency band allocations – particularly insuring that transportation DSRC spectrum at 5.9 GHz remains available to transportation in general and aviation) and a well-constructed approach to security. There are roles for the federal government and its agencies as well as for industry consensus standards and best practices in addressing this challenge.

Infrastructure Access: This challenge will be diminished or amplified by how much societal value is perceived to be derived from these aircraft and by their success at mitigating their potential negative impact on the communities in which they operate. Towards this end, thoughtful placement of vertiport locations that could address "transit desert" locations and truly counteract congestion is key. Technical solutions like low-noise operations (facilitated by electric motors and noise-conscious propeller designs, noise profile-influenced flight path planning, and strategic placement of vertiports) and environmental consciousness are also extremely important and are high on the list of vehicle requirements. The solution to this challenge will necessarily span local, state, and federal government as well as industry and Regulators.

Affordability: While in some ways this is a subset of the Infrastructure Access challenge in that the greater number of people in an urban area that can afford to use an eVTOL UAM service, the less likely resistance to it will be encountered, it is a complex challenge with several facets of its own. Operating and amortized purchase costs are directly related to the regulatory and operational landscape in which these aircraft are certificated and flown. Slow, onerous, shifting airworthiness certification processes will increase vehicle cost. Hindrances to manufacturing, including lack of capital, barriers to accessing international markets, and necessary labor, will increase vehicle cost. Training and/or operational requirements that do not appropriately account for the safety advantages of autonomy and complex systems will increase operational cost. ATC practices that do not facilitate efficient, timely, high-volume flight operations will increase cost while decreasing the usefulness of the entire fleet. As such, the government does have an opportunity to partner with industry to address this challenge, and by extension increase the economic benefit of the eVTOL UAM industry.

Technology Development: While in many ways the technology for these vehicles is available and ready to be deployed, as with any new industry there may still be unforeseen technical obstacles. A high level of technical confidence is warranted, but it would be naïve to assume that no additional challenges, particularly in the electric propulsion and autonomy spaces, exist. Industry at large, including Terrafugia, is working diligently to address these challenges and find and address any lingering obstacles. Future-looking federal agency research funding is one way that the government can assist with this challenge.

8 CONCLUSIONS

In short, we stand at an exciting time in the history of transportation. New technologies, business models, and regulatory approaches are poised to dramatically increase our transportation capabilities. I appreciate being able to share my perspective on this industry and would like to thank you, Mr. Chairman, for the opportunity. I would be pleased to respond to any questions you or the other members of the Committee may have.

9 FIGURES

Figure 1: The Terrafugia Transition® in flight, folding its wings, and in a household garage

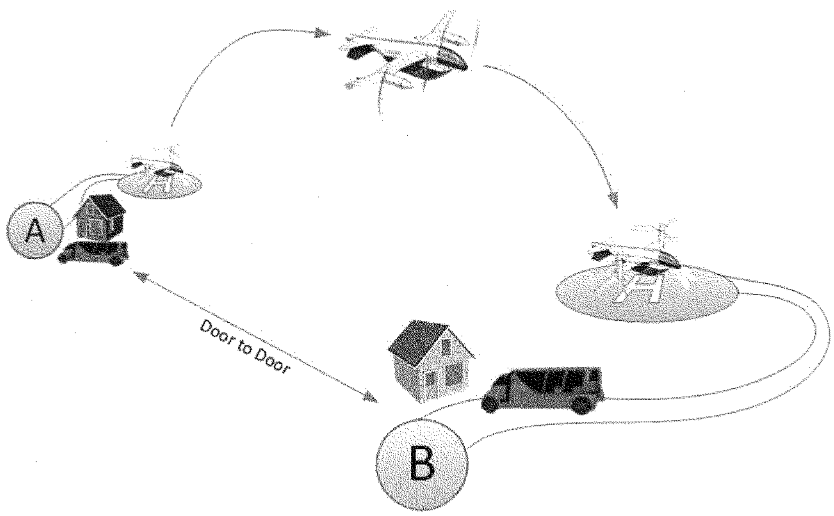

Figure 2: Terrafugia's TF-2 eVTOL door-to-door urban air mobility (UAM) concept

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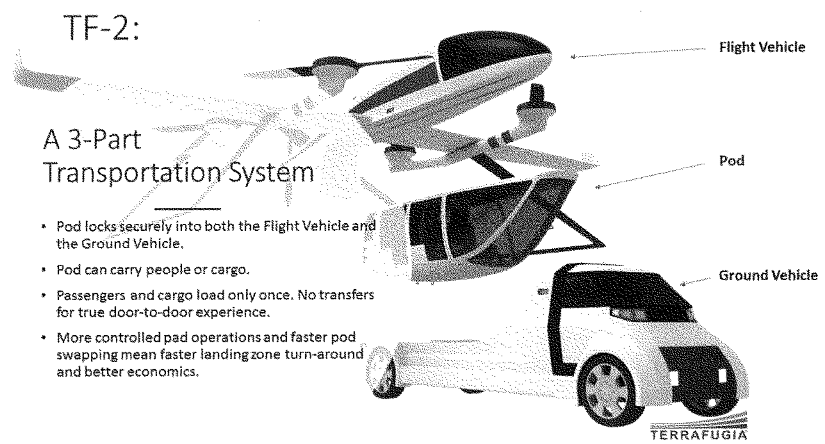

Figure 3: The TF-2 three-part transportation system

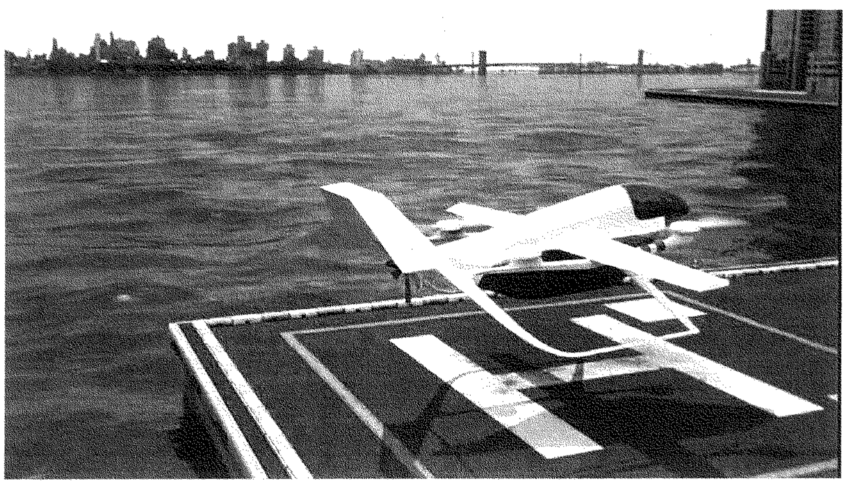

Figure 4: An artist rendering of a Terrafugia TF-2 flight vehicle landing on a VTOL barge near an urban center

10 Enclosure: Presentation Materials

Urban Air Mobility: Terrafugia's Perspective

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Prepared for the House Committee on Science, Space, and Technology
July 24, 2018

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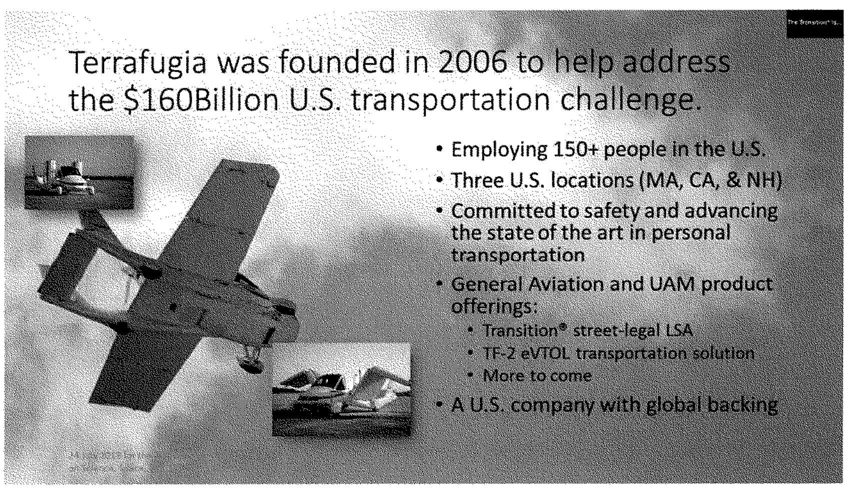

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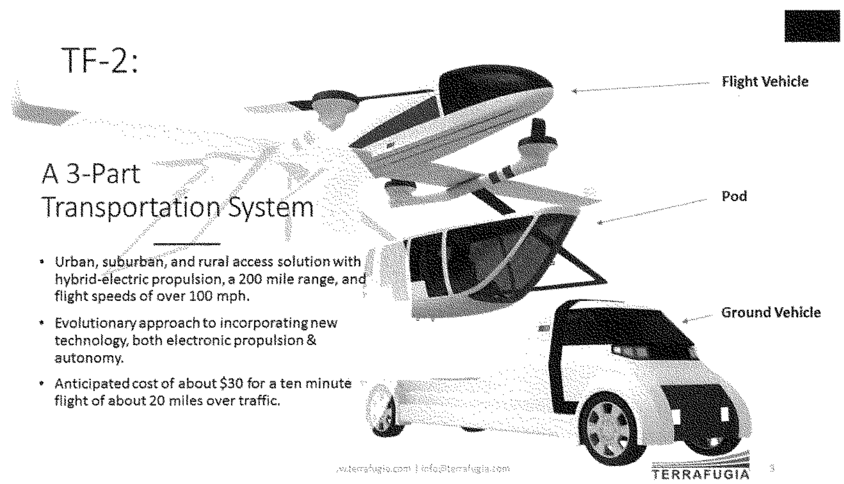

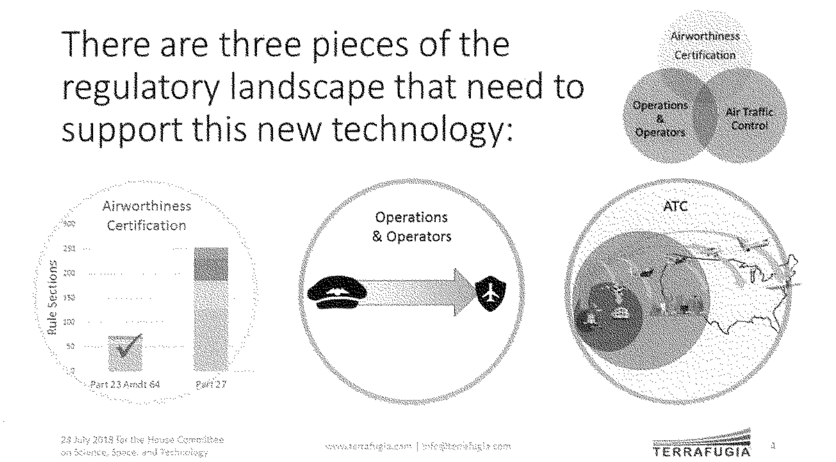

Prepared for the House Committee on Science, Space, and Technology, July 24, 2018
By Anna Mracek Dietrich, Founder & Regulatory Affairs, Terrafugia Inc.
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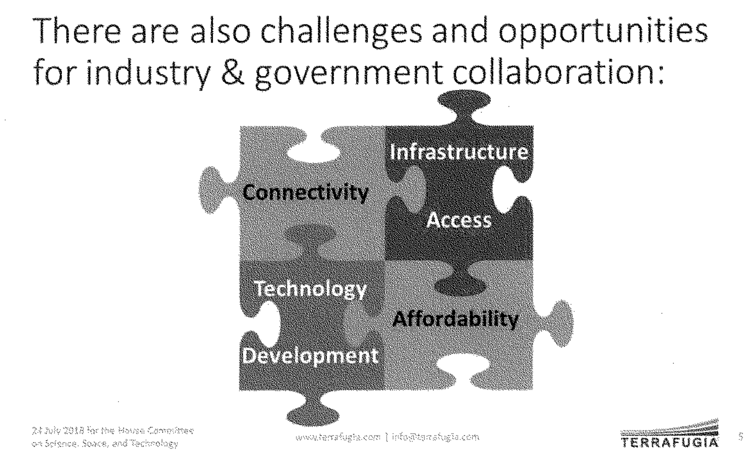

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11 Enclosure: Biography of Anna Mracek Dietrich

Anna Mracek Dietrich is one of the five original co-founders of Terrafugia Inc., a spin-off company of the Massachusetts Institute of Technology in 2006 that has become a revolutionary transportation leader in urban mobility. She served as Terrafugia's first Chief Operating Officer from its creation until 2014 and she currently leads Terrafugia's U.S. regulatory policy engagement. In close collaboration with industry colleagues, Anna has served as a key member of the Federal Aviation Administration's Aviation Rulemaking Committee (ARC) during the agency's significant rewrite of the certification requirements for General Aviation Aircraft (14CFR23). She also holds leadership roles on the ASTM industry consensus standards committees that are responsible for both Light Sport and General Aviation Aircraft. She is currently leading the ASTM effort to create a standards framework for autonomous and complex aircraft systems.

Prior to co-founding Terrafugia, Anna worked with fellow experts to advance pioneering strategies and product development at GE Aviation and Boeing Phantom Works. As a recognized leader in aviation and innovation, Anna was named one of the Boston area's top 15 Innovators by the *Boston Globe*, was one of the 10 women selected for the annual Mass High Tech Women to Watch Award, and has been recognized by Engineers Week New England with their annual Achievement Award. Anna has served in leadership positions on the Board of Directors of Women in Aviation International (WAI) and is an established thought leader on the national and international speaking circuit addressing audiences at prestigious gatherings including TED Global and Uber's Elevate Summit. Anna is a featured expert lecturer at MIT, Embry Riddle, and other academic institutes and universities while promoting advanced careers in STEM.

Anna received her Bachelor's and Master's of Science degrees in aerospace engineering from the Massachusetts Institute of Technology. She also holds a private pilot license.

More professional information on Anna can be found online at www.annamdietrich.com/resume

Chairman SMITH. Thank you, Ms. Dietrich.

Let me recognize myself for five minutes for questions. And let me ask you if you could possibly keep your answers to one minute. I've got lots of questions and would like to get through as many as possible.

Dr. Allison, the first one is for you. What are the advantages of UAM networks over self-driving cars or helicopters?

Dr. ALLISON. Thank you, Congressman, for the question. We see the advantages of this type of aerial ridesharing as the ability to have both higher-speed point-to-point and also higher certainty. So once you take off, the likelihood or the prediction of what time you're going to land is quite accurate versus the ground transportation where you have much more congestion. And so you have both higher speed and lower variance, which adds a unique capability into the transportation network. And these types of vehicles additionally will be quieter, safer, and much cheaper to operate than traditional helicopters, which will make it much more accessible as a transportation system.

Chairman SMITH. Okay. Thank you, Dr. Allison.

Ms. Dietrich, the Transition will be the first flying car available for public purchase. How confident are you that they're going to be available to be bought next year?

Ms. DIETRICH. Well, I'm much more confident that the Transition will be available for purchase in 2019 than I would have been several years ago giving you an estimate.

Chairman SMITH. Okay.

Ms. DIETRICH. We are currently tooling up for production. We do have customers in line for delivery, and as of today——

Chairman SMITH. Okay.

Ms. DIETRICH. —things are on track for that——

Chairman SMITH. And what do they cost and are you taking orders?

Ms. DIETRICH. We are taking orders. We have a team at Oshkosh this morning—this week actually for that, and we anticipate—if you're going to do private ownership model, it'll be typical aircraft pricing so——

Chairman SMITH. What is that?

Ms. DIETRICH. Four hundred thousand dollars, in that ballpark.

Chairman SMITH. Okay.

Ms. DIETRICH. Airplanes are expensive.

Chairman SMITH. Okay.

Ms. DIETRICH. We are looking at other options for being able to use the vehicle——

Chairman SMITH. Okay.

Ms. DIETRICH. —on more of a shared use space——

Chairman SMITH. Okay. And in five to ten years, you hope to have some kind of a public transportation taxi service, is that right?

Ms. DIETRICH. The TF–2 time frame is five to ten years. That's correct. That's the video that we saw this morning.

Chairman SMITH. And Dr. Allison wants to know, won't you be competing with Uber?

Ms. DIETRICH. Well, I think there's a very broad market space, and I think Uber is focused on operating inside city centers, and the TF–2 gives you an opportunity to bring people into that city center from surrounding areas. So I see it as a very complementary service actually.

Chairman SMITH. Wow, you're a politician. Okay.

Dr. Shin, on the urban air mobility, NASA has announced a grand challenge. What does that consist of? What are the details?

Dr. SHIN. Yes, thank you for the question. We envision that private industry investment and the pace of technology advancement is just amazing and great, so we are trying to find exactly what government should be doing to enable the private investment and the progress. So we would like to provide a forum where industry partners can come and check their ability and capabilities. So we—government will provide a certain level of requirements, in—particularly in safety area, in noise area, and areas like that at the system level.

Chairman SMITH. When will that be announced? When you're going to——

Dr. SHIN. We are formulating what sort of exactly the grand challenge should be. As we are speaking, my team has been working on that for a month, and we are hoping to announce the intent by early next year so that industry partners can prepare.

Chairman SMITH. Okay.

Dr. SHIN. And then toward the end of next calendar year, we're hoping to announce the grand challenge.

Chairman SMITH. Okay. That'll be a good incentive.

Mr. Thacker, I know you have a partnership with Uber to design vertical takeoff or landing vehicles. My question for you—and obviously, Bell has changed its name from Bell Helicopter to just Bell. That may be part of the answer, but do you think the days of the helicopters are limited or are there still advantages to helicopters?

Mr. THACKER. So the days of the helicopter are not limited, but we do see the world changing, and Bell is much more than helicopters. We already are more than helicopters with tiltrotor, with the V–22 and the V–280 for the Army and Marines' future vertical lift needs.

But beyond this, this move in technology and convergence of electric, hybrid, and distributed propulsion allows a new breed of vertical takeoff and landing vehicles, one's for markets like the Uber network but also for carrying cargo and logistics, as Dr. Clarke mentioned. We see that as a tremendous opportunity for our business and one that, as a legacy leader in vertical lift, we should be leading as well and so thus the change from Bell Helicopter to Bell.

However, from a heavy standpoint from things that require large amounts of lift, there will be hydrocarbon-burning helicopters around for a good long time.

Chairman SMITH. And perhaps long distances as well?

Mr. THACKER. Absolutely.

Chairman SMITH. Okay. Thank you, Mr. Thacker.

Dr. Clarke, what kind of public-private partnerships can we expect in coming years?

Dr. CLARKE. I think, you know, it's not realistic to expect FAA to be expanded to actually dealing with air-traffic control in an urban environment, so I do believe municipalities will be involved for liability reasons, and I think there are a lot of companies out there working on ideas for air-traffic management. And the NASA UTM program has been very instrumental in figuring out how to get people to communicate and different entities communicate together.

So ultimately, I see like a cable model where——

Chairman SMITH. Yes.

Dr. CLARKE. —some part of an urban area will be allocated a space for them to provide a service of air-traffic control. Obviously, the regulations have to be—the proper regulations have to be put in place and the communications and handoff from one area to the other will have to be worked out. But I envision a cable model in a short sentence.

Chairman SMITH. Okay. Thank you, Dr. Clarke.

That concludes my questions. The gentlewoman from Texas, the Ranking Member, is recognized for hers.

Ms. JOHNSON. Thank you, Mr. Chairman.

Dr. Clarke, you indicate in your prepared statement that increasingly autonomous capability will be necessary as UAM services expand. Could you highlight what you believe makes that necessary? What will—what kind of attention will be given to the safety risk? What role should research play in mitigating such risk? And who should do this research?

Dr. CLARKE. Well, I'll start with the last one. I personally believe NASA is in the right position to do that research. So I'm going back to the start of your question, let's start with the commercial side, the Uber side of things. Economies of scale dictate that you'd like to move first to one operator and then no operator of a vehicle. And if you go to one operator, the requirements to train that person to the level of a commercial pilot are onerous and quite expensive. And you have to pay them, and we already have a forecast shortage of pilots. So that drives you there to more autonomous vehicles so that you don't have to have somebody with a commercial pilot license and 1,500 hours operating a vehicle. So you have to then trade that off with some more autonomy to complement their skill sets.

And then when you go to no operator or at least nobody in the vehicle operating the vehicle and remote supervision, you have things like loss of communication that become issues, so the vehicles themselves have to be able to operate without a linkage to somebody on the ground. So both of those things, moving to a single pilot, moving to pilots with less training than our current commercial pilots, and going towards completely autonomous systems. I mean, systems that have linkages with the ground which can be lost drive you towards autonomy.

And the research needs to be done to figure out how to get—the big thing is how do we get vehicles that, when faced with the situation, don't just say "does not compute" and shut down, right? We want vehicles that, when faced with a situation, act more like humans, which basically try to figure out what the issues are, try to figure out where the constraints need to be relaxed, and what needs to be done to at least get them to a safe point, a safe mode, which we've done for many years on the space side where, when things happen, there's always a safe mode to revert to. So that in summary is where I think.

Ms. JOHNSON. Thank you very much.

Dr. Allison, in Dr. Clarke's prepared statement he indicates that potential UAM service users are likely to prefer the vertiport locations convenient to their homes and where they're headed. How should that convenience of the UAM users be balanced with community concerns in choosing vertiport locations?

Dr. ALLISON. Thank you, Ranking Member, for your question. This is a very important concern and something that we've spent a lot of time looking into. One of our strengths at Uber is that we do a lot of analysis, simulation and understanding of transportation networks, and so we've made as a core of Elevate an ability to analyze, to infuse together different types of data for different communities that we're looking at in terms of restrictions and noise sensitivities and things like that. To actually determine where an optimal place is based on demand, as well as community considerations are to place the vertiports as we develop our network.

And so we want to do this in partnership with the local communities, which is why we've had a very strong engagement with both Dallas-Fort Worth and Los Angeles to actually determine the right way to do this and to do it in a way that works hand-in-hand with local communities to build a service and a network that everyone's very happy with.

Ms. JOHNSON. Thank you. Based on FAA's experience with community resistance to the concentration of flight tracks and all of the application of next-gens, of tracks, and performance-based navigation techniques, it appears—and I don't know what it's going to cost. I don't know if you know yet, but it does appear that the people who might be able to use it are also the ones that do the most complaining about air-traffic noise. And so how do you plan to mitigate that?

Dr. ALLISON. We have as our basis for what we're doing kind of a deep view that community engagement is very important from the very beginning, and so part of our desire to roll this out in a systematic way is to start in places where there is the right level of engagement and the right level of support in the community and to demonstrate the low-noise capabilities and the integration into the local transit system in a way that demonstrates the utility and the overall value proposition of this type of transportation to the wider community. And so that's the approach that we're taking as we roll this out.

Ms. JOHNSON. Thank you very much. My time is expired.

Chairman SMITH. Thank you, Ms. Johnson.

The gentleman from Oklahoma, Mr. Lucas, is recognized for questions.

Mr. LUCAS. Thank you, Mr. Chairman.

I represent—and I guess I should direct my question to Dr. Allison and Mr. Thacker and Mrs. Dietrich— I represent a part of the country that benefited greatly from the establishment of the U.S. highway system. And when you're in Oklahoma, of course you're on the old historic Route 66, the commerce road from Chicago to Los Angeles, and it dramatically expanded the availability of services, the nature of the economy in rural America.

So let's talk for a moment about—and I know our initial focus is on the urban areas—but let's talk about how long you would expect the benefits of urban air mobility to work from the urban zone out into the suburbs, the rural areas so to speak.

Mr. THACKER. So I'm happy to take a stab at that——

Mr. LUCAS. Please.

Mr. THACKER. —and then let my colleagues join in. Honestly, we see the timeline for some of the applications being very similar. At Bell we are developing all-electric solutions for applications like the Uber network, but we're developing hybrid electric solutions with modular propulsion to extend the range. So the ability to deliver goods and services, provide emergency medical capabilities, things that general aviation already provides to rural communities with these vehicles and with this system, it should be available in a similar time frame. In reality, it may be available to some degree sooner because, from an operational standpoint, we will begin operating over lightly populated areas before we operate over heavily populated urban areas.

Ms. DIETRICH. And I would second what Mr. Thacker said. I think that there is a real possibility to bring more rural areas, more into some of the advantages that you have in the urban areas, getting access to hospitals, more expedited cargo delivery, things like that. I think this industry has the ability to serve those areas very well, and I agree with the timing and I agree with the hybrid propulsion solutions that provide a longer range. You know, TF–2 has a range of around 200 miles. Those sorts of solutions will bring access to those communities probably on the same time frame as the all-electric versions to city centers.

Dr. ALLISON. Yes, our network is focused on higher-density areas because a lot of the ability to drive utilization and load factor into vehicles is one of the ways we're able to drive costs down at least in our predictions on a cost per passenger mile. So certainly, as we extend to less densely populated areas, we'll have to revisit some of those assumptions and look at the way the network flows are modeled in—as the density decreases.

Mr. LUCAS. This question I address to the whole panel. And I go back once again to Route 66. When that was initially laid down, the average automobile that would have puttered down the road in Oklahoma would have been a Ford Model T, very simple four-cylinder, minimal mufflers, no emission control essentially whatsoever, but a very effective mass-produced automobile that the country—for that matter, the world—adopted and it led to an explosion and huge advancements in automobile technology.

Assuming that this is a similar path moved forward a century with the initial success and the mass adoption—because we all tend to move as a group in this great country when it comes to new technology, it seems—let's go back once more to that issue about how we manage air traffic. If we suddenly go from the Model T's of the 1920s to the automobiles of the '30s, '40s, '50s, we'll have a dramatic explosion in the utilization of the airspace.

I live in a part of western Oklahoma where, while it seems very thinly populated, we are under a military air reservation. We have training flights, primary pilots, the transport Air Force cargo planes that train all the time. We've got the East-West traffic, the commercial stuff with the higher elevations, which I realize is above where we're talking about going, but let's discuss for just a moment the public-private sector relationship, how we think they'll advance. Can we keep up when it comes to managing that air-traffic flow if there is an explosion in utilization?

Ms. DIETRICH. I thank you for bringing up the history of the automobile and bringing that industry online because when first those Model T's were rolled out, we didn't have the transportation infrastructure on the ground that we do today either. We didn't have stoplights at every corner.

Mr. LUCAS. Exactly.

Ms. DIETRICH. We didn't have, you know, the rules of the road——

Mr. LUCAS. And my great-grandfather said it was——

Ms. DIETRICH. Yes.

Mr. LUCAS. —a silly fad at the time, yes.

Ms. DIETRICH. Exactly. So we have a history of being able to kind of evolve very quickly in these ways, and I think we will see something similar with these vehicles. And I think we can do a lot today in laying the groundwork and preparing ourselves for them, but I think we also do have to stay a bit nimble on our feet and be prepared to adapt as we see where this industry truly goes and where the demand really surfaces.

So I think we can—and I know the work is being done here is definitely in line with preparing us for that, but I think at the same time we need to be willing to accept the fact that we don't exactly know how this is going to play out and that there will be things that arise that we haven't been able to foresee and that we should be able to adapt as we go and have confidence in our ability to do so.

Mr. LUCAS. Thank you. My time is expired, Mr. Chairman.

Chairman SMITH. Thank you, Mr. Lucas.

The gentleman from Virginia, Mr. Beyer, is recognized. Now, I know the gentleman has a certain interest in car dealerships. When it is he going to start selling flying cars?

Mr. BEYER. Yes, I just came to see if I could get a franchise today, Mr. Chairman.

Dr. Allison—this is relevant for everyone, but Dr. Allison, I'm picking on you. And I live in northern Virginia, which has the longest commute times in the country, the second-worst congestion. You come in I–66, I–95, I–395, the GW Parkway in the morning and it's just bumper-to-bumper sometimes all day long. So I keep trying to imagine—and often, when I'm in traffic, I imagine moving to the third dimension. But I'm trying to figure how many cars do you really need to remove from a congested I–95 to get it to actually flow?

And when you look at the size of the vehicles that we've seen in the videos, which are going to require more front space, rear space, left, right, and above and below just because they're airplanes rather than cars, it'd be fascinating to see the video that shows how you've taken, say, 20 percent, 25 percent of the cars off and how incredibly congested the airspace goes above, especially if you assume—and I do—that the communities are going to insist that the lanes are defined for these vehicles, too, that you're not just flying over neighborhoods that—as right now, the helicopters are supposed to fly along the existing corridors.

I can see why you need autonomous, too, because if you start putting all these people up in the air that are texting while they're flying their plane, it can become incredibly difficult so——

Dr. ALLISON. Thank you, Congressman, for the question. So the vision that we have is that this will happen progressively over time, so it won't start with, you know, many, many, many aircraft flying around. It will start with a few, and we'll build up the systems as we learn, as Anna was saying actually.

However, if you think about the three dimensions of the space available to sequence and structure—and we've done lots of simulations of this as well—vehicles flying between different points in the point-to-point type of a network, at a couple thousand feet you don't actually get to the same type of congestion that you see on the ground because there's just a lot more space and you can space things out.

And one of the features of the types of vehicles that we're all talking about here, these vertical takeoff and landing electric vehicles that convert from rotor-borne flight in the takeoff and landing phase to wing-borne flight in the cross-country phase is that they get dramatically quieter and more efficient as they're flying in vertical flight. So when they're up at cruise altitude and flying along, they're very quiet, you basically don't hear them. They're not the same as a helicopter where they make a significant amount of noise through the whole segment of the flight that they're on.

So those different features, the fact that there's a lot of space in order to space things out, the fact that they're pretty quiet, and they go a lot faster than cars, too, so we're talking 150 to 200 miles an hour in terms of the cruise speed allows the airspace to soak up a lot more traffic than——

Mr. BEYER. Okay.

Dr. ALLISON. —you'd expect based on the way ground networks, which are basically kind of quasi-one dimensional tworks clog up with cars.

Mr. BEYER. All right. Thank you very much.

Dr. Clarke, picking up on what Dr. Allison just said, in your testimony you talked about the similarities between helicopters and urban air mobility and that a likely side effect of urban air mobility could be the constant drone of aircraft noise. I don't need to tell you that the number-one concern in my district is aircraft noise followed closely by helicopter noise. How do we assure those folks that—you know, our research into UAM is really focusing on the noise piece, too.

Dr. CLARKE. Well, that's part of the reason why I suggested in my testimony that there needs to be research and a tool—and this hasn't—it's not going to be just one company or one manufacturer. It has to be a government or the community, broad community, accepted and verified tool for optimizing the trajectories to make sure that the noise level is above the ambient. I mean, in the end, people worry about what's above the ambient. I mean, you look back to the Grand Canyon, you know, people said, oh, the airplane is quiet, the helicopter is quiet, but if it's above 35 DB or 40 DB in the afternoons, people complain. And that's very quiet, but people have gone to the Grand Canyon for that natural quiet. And so it—you always have to match the noise level with the ambient, and we have to—we can do it, but it will require a lot of optimization of where the vertiports are, what routes they're flying.

And I would add privacy to one of those things because we actually don't know how people are going to react to vehicles being that close to their houses. And we have to do some studies to actually figure it out. And in fact we don't know how people are going to respond to vehicles flying, you know, at 400 feet or 1,000 feet on a long distance at that constant altitude because we're accustomed to vehicles basically taking off and going to much higher altitudes.

So there's work to be done to understand people's responses, and then there's work to be done to model, and then there's work to be done to optimize the trajectories because, ultimately, we want to enable UAM. I mean, I'm an airplane guy, but——

Mr. BEYER. Yes.

Dr. CLARKE. —we want to do it right.

Mr. BEYER. It is going to change sunbathing in the backyards, though.

Dr. CLARKE. Yes, I suspect it will.

Mr. BEYER. Mr. Chairman, I yield back.

Chairman SMITH. Thank you, Mr. Beyer.

The gentleman from Louisiana, Mr. Abraham, is recognized.

Mr. ABRAHAM. Thank you, Mr. Chairman. And I appreciate the hand-up you gave of the history of the flying car going back to 1947. I know in 1949, Moulton Taylor had an Aerocar that actually flew. And to your James Bond fondness, as—which I am—if you remember, The Man with the Golden Gun had a flying car in that movie also.

Ms. Dietrich, I was there when Terrafugia premiered their car at Oshkosh. After votes Thursday, I'll also be flying to Oshkosh, and your booth is always the most popular. There's always a large crowd, so you certainly have the attention of the aviators of the world, so I think we're getting close.

And I'm not too worried about the noise level. I know you guys will have to get it right from a business standpoint or you won't survive. That's going to be driven by both civilian population, as Dr. Clarke alluded to.

I guess my concern—and it's been brought up—is transitioning from an uncontrolled airspace where basically you can do what you want to, to a controlled airspace and whether it's class delta, which is in a small community or whether it's class B, as you guys know that are on the board there, that airspace is controlled from surface up to 4,000, up to 10,000 in class B. So ATC has control in even a small city from surface on up. And a day like today where it's cloudy, the ceiling is low, I'm concerned that if you have an autonomous vehicle that, you know, gets lost in the clouds, it gets basically disoriented, and unfortunately, you know, bad things happen.

Ms. Dietrich, I'll I guess go to you first. I'm assuming that for the Terrafugia Transition car a pilot's license will be required to purchase that car?

Ms. DIETRICH. Well, thank you for the question. Thank you for the kind words. Yes, for Transition, our first product, that's a light sport aircraft, so you will need a sport pilot license or better in order to fly that aircraft. And depending on the qualifications of the pilot in the aircraft, you wouldn't be flying that particular aircraft in a day like today.

From an instrument—meteorological-conditions perspective, autonomy is actually a safety benefit in those areas because all of the sensors that you would use to fly an aircraft on a sunny day are the same as the ones you would use to fly on a cloudy day. So autonomous capabilities can actually increase safety in bad weather, which is one of the reasons why we're considering incorporating them not just in these urban air mobility vehicles but looking at ways to bring them in to broader general aviation as well.

Mr. ABRAHAM. And I'll agree with that. I fly Cirrus, which has wonderful avionics and certainly can make me a much better pilot in conditions like this than me flying myself, so, you know, I can't argue there.

And we know that in you all's world we're having to convert to ADS–B Out by 2020, and if you ADS Out—and cars—flying cars and certainly airplanes can talk to each other, so that may alleviate some of the burden on air-traffic control.

Again, I worry also, you know, about the weight and balance, if you get somebody that does not know aerodynamics and they get into an autonomous vehicle that overloads its weight and balance capability, then you're in a dangerous situation.

And, Dr. Allison, I know Uber and companies like yours are thinking along those lines. And I'll just let you comment.

Dr. ALLISON. Sure. Thank you, Congressman, for your question. Those are all very important considerations, and we are certainly going to take a crawl-walk-run approach to this as we develop the networks. We will start with demonstration flights initially, experimental flights basically in conjunction with our partners in the partner cities, and then as—we will learn from that as we move toward the 2023 launch of the commercial flights that we're ambitiously projecting.

So these questions of weight and balance, those will all have to be figured out by learning, by actually simulating these things and testing them in practice as we roll toward that initial startup commercial service.

Mr. ABRAHAM. And for you and Ms. Dietrich, are you planning on building these cars under part 23?

Ms. DIETRICH. Yes, sir. Part 23, amendment 64, is a good fit for these aircraft. There's about 80 percent of that rule that applies directly without any need for modification, ten percent that's just simply not applicable like landing on water. And then there's about ten percent of that rule where we'll need to work with the FAA for special conditions or other consideration where it just wasn't originally contemplated. But by and large it's a good fit.

Mr. ABRAHAM. And the FAA has helped a little bit with the regulation, part 23, as far as that?

Ms. DIETRICH. Yes.

Mr. ABRAHAM. Dr. Shin, do you have any comments on any of this?

Dr. SHIN. No, I think I support everything the other witnesses mentioned. I think I want to point out that this is a great opportunity for the country, that from very high-tech but low-volume industry that aviation has been accepted, general aviation part. We are actually looking at the possibility of turning the aviation industry as a whole from—it's still very high-tech—but extremely high volume just like automobile industry. So I think government really needs to find a way to enable this new capability for the country, our national economy, and jobs.

Mr. ABRAHAM. Well, I agree. And look, I think it's an exciting time and I wish all you guys the best of luck. I think the future is bright, so thank you very much.

Mr. Chairman, I yield back.

Chairman SMITH. Thank you, Mr. Abraham.

The gentleman from California, Mr. McNerney, is recognized.

Mr. MCNERNEY. I thank the Chairman for having an interesting hearing and for passing out party favors as well.

One of the things that worries me about this subject is energy consumption. I mean, these things are going to—the—a flying vehicle is going to take a lot more energy than a surface vehicle. Can someone address the differential and how much more energy it's going to take to get somebody from point A to point B on a flying vehicle than a surface vehicle?

Dr. ALLISON. I'm happy to jump in.

Mr. MCNERNEY. Sure.

Dr. ALLISON. Thank you, Congressman, for the question. So, actually, the amount of energy per passenger mile is similar to an electric car, so for an all-electric version of these vehicles. Because they have to be very efficient in order to make it work essentially, that you have to design the aerodynamics and tailor the energy consumption for the vertical takeoff and landing phases of this, that it's not substantially different than a surface vehicle when it's all said and done because of the much more enhanced aerodynamic design and tailoring that has to be done for these types of air vehicles.

Mr. MCNERNEY. So speaking of aerodynamics, I mean, how much—how fast do you have to go to get one of these vehicles off the ground? I mean, there's a speed issue here which must—yes?

Dr. ALLISON. So the concept of most of what we're talking about is to take off and land vertically, so they actually take off at zero speed just like a helicopter and then transition to forward flight either—through different means so the different—different of our vehicle partners are approaching this problem in different ways. We have different types of vehicle concepts that accomplish that transitioning regime differently. But then once they're wing-borne, they fly like an airplane on the wing, which is much, much more efficient than flying rotor-borne, and that allows them to be lower noise and higher performance.

Mr. MCNERNEY. Well, thank you. And again, I don't know who to ask this question of, but according to a 2015 GAO report, newly developed aircraft may be particularly vulnerable to cyber attacks and cyber issues. If a hacker is able to overcome an aircraft's firewall, it could cause significant damage. Where do we stand with regard to security on these and being able to provide the security that we need to make sure that there's not a safety issue?

Dr. CLARKE. So I'll take that. My committee, the one I chaired—co-chaired in 2014, I identified security as being a major issue. I have briefed the then-DNI on this topic and I can't talk about that here, but I know that work is being done very extensively looking at this. As you rightly point out, there are vulnerabilities that need to be addressed.

You know, in the old days, air-traffic control had security from obscurity in that nobody could get in, and therefore, you couldn't do anything. Now that you have lots of wireless networks and IP protocols, there are opportunities, and people are working hard on this I know on this topic.

Mr. THACKER. Yes, I agree, and I think the key with it is an ongoing vigilance because it isn't a static target that says——

Mr. MCNERNEY. Right.

Mr. THACKER. —we've solved cyber and now we're ready to go forward. It's going to be something that we have to continue to adjust and adapt as we go forward because the threats will continue to adapt as well.

Mr. MCNERNEY. So I've asked about energy, I've asked about cyber. What about cost? Is there going to be a comparable cost of a flying vehicle versus a surface vehicle?

Dr. ALLISON. Thank you for the question. We—so what we have announced—we—at the—a big event we did in the spring is that our initial targets for rollout of this service, we kind of have announced a series of target-priced steps that we believe we can essentially match UberBLACK pricing in the initial rollout of the—in the target cities, Dallas-Fort Worth and Los Angeles, by increasing utilization and increasing the load factor by utilizing pooling out of our ground network. We think we can get to UberX-type pricing, which is around, say, $1.50 per passenger mile roughly speaking. And that's enabled by aggressively pooling to drive load factor into the vehicles and get the utilization up.

And ultimately, we see at scale with improved manufacturing techniques that are more akin to the automotive industry, that we can be competitive with the costs and again on a passenger-mile basis of car ownership, which is something like 44 cents a mile I think AAA says right now.

Mr. MCNERNEY. Okay. All right. Mr. Chairman, I'll suppress my next question and yield back.

Chairman SMITH. Thank you, Mr. McNerney.

The gentleman from Texas, Mr. Babin, is recognized for his questions.

Mr. BABIN. Yes, sir. Thank you, Mr. Chairman. I appreciate that and appreciate all of you witnesses. What a fascinating topic.

Dr. Shin, is the United States maintaining its leadership role in the growing and evolving market for this aviation market? With regard to urban air mobility, will we be first to launch operations or might we lose out to some other country? And if so, what nation, and what are the consequences of not being first?

Dr. SHIN. Well, thank you for the question. I think it is fair to say—and I do believe that the United States still is leading the—this new potential market and capability from that perspective because, as I said in the oral testimony, we have the best minds and best technologies and best entrepreneur spirit.

However, I even coined—I made up an English word called most developed country syndrome, so we are the most developed country in the world, and along with that, we have a lot of interests that some other countries may not care that much or they will be willing to relax some of those concerns. So the name of the game in this area in my view is since entry cost is very low compared to regular commercial airline business, most—probably most developed countries or developing countries can actually start this industry if they are willing to lower or relax the constraints and issues from a regulatory perspective, some safety perspective, and so on, so that is indeed a concern. And as you all know, some of the countries are jumping ahead and allowing even U.S. companies go to those countries.

Mr. BABIN. Who are those countries?

Dr. SHIN. They are Australia, New Zealand, and some of the European countries willing to do that, and Singapore or so—so some of the countries—again, I'm not suggesting they are lowering the safety standard, but they're willing to——

Mr. BABIN. Okay.

Dr. SHIN. —jump ahead. So that is a concern. But I do believe we have the—still the way to scale this up, as Dr. Allison and——

Mr. BABIN. Okay.

Dr. SHIN. —Ms. Dietrich talked about.

Mr. BABIN. Thank you. Once the UAM system is in place and multiple options exist for people to travel by air taxi, how long will it take before people will be able to own and operate their own VTOL vehicles? You may have already touched on this a little bit. I had to leave the room. And how much more complicated will it be to do the air-traffic control management, Ms. Dietrich?

Ms. DIETRICH. Yes, thank you for the question. I think that many of us in this space are not anticipating a private ownership model for the vertical takeoff and landing aircraft. I think we're seeing those as probably being cost-prohibitive for an individual owner, as well as if this system works the way envisioned, it won't be necessary. You'll be able to get the functionality without the headache and without the upfront expense.

Mr. BABIN. Right.

Ms. DIETRICH. So I do expect that these vehicles will be really dramatically increasing the number of aircraft that we see in the general aviation industry. My company alone is looking at deliveries on the order of a few thousand a year. That's currently basically the entire size of the GA industry each year. So this industry will rapidly become more of the norm than what we see in legacy aircraft today, and I think we're going to have to be conscious of that as we think about new constructs of both ownership and usage of these vehicles in that what folks typically think of as smaller planes in general aviation today will become a small piece of a much larger industry that brings the benefits of transportation by small aircraft to many more people but is not what we currently think of.

Mr. BABIN. Okay. Thank you. And Mr. McNerney had touched on this a little while ago, but just to be more specific, cybersecurity is a topic of serious concern whenever we discuss technologies, especially those that are new and nascent. How will the VTOL vehicles be protected from cybersecurity attacks, and who will be responsible for that protection? Will it be the vehicle manufacturer, the company that runs the operating system, the FAA, or someone else? And who would like to respond to that? Dr. Clarke?

Dr. CLARKE. Sure. I'm a faculty member, you know. We always——

Mr. BABIN. Right.

Dr. CLARKE. So precedence is that the operators ultimately are going to be the ones that are responsible. I'll give you a quick example. Every 28 days, we update the database of waypoints in the country that goes into flight management system, and even though the person putting it in might actually make a mistake, if something happens, it's the operator of the airline that's responsible because——

Mr. BABIN. Sure.

Dr. CLARKE. —they need to check. So they actually have staff members checking that database every 28 days, so that's what precedent would suggest. Ultimately, it's going to be a partnership. The one thing about aviation is that it truly has been and will continue to be a partnership between regulators, operators, and manufacturers. And there—like I said, there are people doing work, which I can't talk about, on the cybersecurity issue, but there are—they're going to be—it's going to be a partnership, and people are going to basically figure out how to do some tests of things coming in and out. Communication is one thing. There are companies thinking about using in-flight entertainment systems for doing communications of flight-critical information. There are people working on how to do that and keeping track of whether there's been nefarious tampering with the——

Mr. BABIN. Okay.

Dr. CLARKE. —data, et cetera.

Mr. BABIN. Okay. Thank you very much. And I yield back, Mr. Chairman.

Chairman SMITH. Thank you, Mr. Babin.

The gentleman from Pennsylvania, Mr. Lamb, is recognized, and I have a quick question for him. Did you hear you were going to get a flying car if you attended the hearing today?

Mr. LAMB. Well, I actually came here in a flying car, but it was a little late so that was why I showed up a little late, so I guess there's more research——

Chairman SMITH. I just want you to know there's only three left but you made it.

Mr. LAMB. Oh, wow. Okay. Dr. Clarke—or anybody can take this but I wanted to address it first to Dr. Clarke. This actually seems like an industry that could create a fair number of jobs both in terms of the operators themselves, the engineers, designers, manufacturers. Does anyone have a sense of the potential impact in terms of numbers of jobs that we could be talking about, let's say, in the next decade?

Dr. CLARKE. I can't give you specific numbers so—but I can tell you that I've been a faculty member for 21 years. This is the most excited I've ever seen students around aviation. I mean, people are always excited about space, but this is the most excited I've seen people around aviation. And you know I think there's a great potential for jobs. I mean, I have undergrad students who are thinking about doing a startup. In fact, they've been building a wind tunnel in somebody's—they are looking for a flying vehicle which looks like a motorcycle, and they're trying to figure out where to move that wind tunnel. In fact, they sent me a message like, "Do you know somebody where we can move this wind tunnel?" They're funding themselves, so there's a great excitement. There's great potential.

And, you know, to Uber's credit, they have basically said we're not going to build a vehicle but we're going to provide specifications and leave it out there for lots of others to do that.

And the—you know, the challenge, the Boeing challenge around a flying motorcycle, that's generated a great deal of interest. And so I think the potential for jobs are tremendous. I can't give you a number because that's not—maybe the guys here who—will know how many people they're going to hire will tell you.

Mr. LAMB. Anyone? Anyone have——

Ms. DIETRICH. I can offer a little bit of information. So since Terrafugia has really entered this space, we've been hiring on average five people a week, and we don't have plans to slow that down. So that's just one company.

I would say that we're probably talking—when this industry is mature across all of the participants—between two and three orders of magnitude larger than the existing GA industry just to give you a sense.

Mr. LAMB. And what about in terms of encouraging domestic manufacturing of all the equipment that we're going to need for this and the supply chain? Anyone have any thoughts on that? Mr. Thacker?

Mr. THACKER. Yes, so, again, you think about the production volumes for existing aviation, general aviation in particular on—in numbers of tens, if you're at 100 a year, you're having a pretty stellar year. Maybe at the smaller end of light GA, you get into a few hundred a year. When you're talking about hundreds to thousands a year of somewhat larger vehicles that we're discussing here, it's a tremendous opportunity from a manufacturing standpoint for our country as well.

Mr. LAMB. Anyone else?

Dr. ALLISON. Just to amplify that a little bit, from our perspective we've been doing a lot of demand studies, so we've built these demand models. We look at trip flow. I actually presented some of this at the event in the spring for the L.A. region. But our studies suggest that at scale when this network is fully developed and it's soaking up, you know, possibly even double-digit percentages of overall trip flow in a region like L.A., that you could be talking about not just thousands but tens of thousands of vehicles active, enough demand to support that.

Now, it would take a lot of time to get there, obviously, building out the network, but that's an incredible number compared to what the industry can produce right now. And so we have to see this industry grow significantly, as Ms. Dietrich said, multiple orders of magnitude, and it makes a lot of sense to produce these vehicles closer to where you're deploying them as well from a logistics standpoint because they're generally larger than cars and harder to ship and things like that, so I think there's going to be a lot of impetus to build out manufacturing capabilities here in the U.S. to be able to produce the volumes that this service or this type of transportation will demand.

Mr. LAMB. Dr. Shin?

Dr. SHIN. Yes, if I can just add one more point, I think it is important for all of us to recognize that when we use urban air mobility, it truly includes from smallest UAS to air taxi and personal air vehicles and commuters and all those things that truly changing the landscape of aviation today. So as you are probing about the jobs and supply chains and all that, I think we need to really look at the holistic way of package delivery to passenger carrying small and large. And another question about the rural area, all these things should be considered as this air mobility. For the time being, we're using urban air mobility, but I think that opens up all these possibilities.

Mr. LAMB. Thank you. Mr. Chairman, I yield the remainder of my time.

Chairman SMITH. Okay. Thank you, Mr. Lamb.

The gentleman from Florida, Mr. Webster, is recognized for his questions.

Mr. WEBSTER. Thank you, Mr. Chairman, for doing this committee hearing and presentation. This is an awesome and very interesting subject.

Dr. Clarke, I went to Georgia Tech, so we've sort of crossed paths. And Representative Massie, who was here earlier, went to MIT when you did. He was a double-E. But anyway, we're glad you're here. I got an opportunity to speak to the graduating class last year in the May graduation. That was a real thrill.

Anyway, you mentioned in your presentation four different—well, not obstacles, hurdles, let's say—to cross. Do you see any of those that are insurmountable?

Dr. CLARKE. No, I do not. I think they're all doable. I will say, you know, one of the things—the whole issue of autonomous operations versus decision-making is one of those that is particularly challenging because, you know, a lot of the things that people think about autonomy is really autonomous operations, you know, it's computer code, it's been validated, verified. It operates under certain conditions, and when things are unusual or in a situation it doesn't—it says, "I can't do anymore; I give up."

Mr. WEBSTER. That'd be a little scary.

Dr. CLARKE. It is a little scary. And so there is work—I just—the National Science Foundation just announced a major program on autonomous decision-making just this past week where they're trying to actually get the fundamental research done and to basically decide how systems should decide to operate.

So, you know, I think the ultimate idea or exemplar of what autonomous decision-making are kids. I have twins and they're 11 and they're getting to that stage where they're getting to the autonomous decision-making. And you always think of yourself, which you've basically given them, you know, life lessons. You teach them how to think, not what to think but how to think, and that's really the great challenge in autonomy, teaching or building systems that actually learn and adapt and can adapt to situations they have not seen before. And so that's the challenge that I think is one of the biggest ones, but there is work being done both at NASA but, like

I said, the National Science Foundation just launched a major effort in this area, and I don't think it's insurmountable. It shouldn't surprise you that I have some ideas about how to solve that problem. So I don't think it's insurmountable.

Mr. WEBSTER. So do you see them running on parallel tracks and like they could be separate solutions to each one, not necessarily waiting on the other one to be solved?

Dr. CLARKE. Right. No, and that will be the case and that has been the case where, for example, in autonomous cars we have a lot of algorithms in place that only operate under certain conditions, and when they get close to the edge, they basically say to some human supervisor, look, I can't get a solution.

I personally believe that autonomy is more than just handing it over to the human when you can't figure it out. I think, you know, there's lots of opportunities for autonomous systems to help humans identify when they're getting close to the edge and basically staying away from the edge. And so there's—there are opportunities in the near term to introduce autonomy within limited settings but then gradually increase the level until the point where we get to full autonomous decision-making.

Mr. WEBSTER. Do you have any predictions on when that point will be?

Dr. CLARKE. When? My usual guess is around ten years, five to ten years, given the level of effort that is now—that I'm now seeing starting to pick up. Obviously, that will be—have to be a sustained effort to keep it going, but I think five to ten years we will get to the point where we'll have autonomous decision-making at the level that I would feel comfortable getting—I mean, getting on an airplane without having to worry about that.

Mr. WEBSTER. You'd be willing to get on it and ride it?

Dr. CLARKE. Oh, yes.

Ms. DIETRICH. If I may build on that just briefly, we're taking an approach with our designs that allow this spectrum to happen organically, so initially, we are going to have a commercial pilot on board the aircraft that's responsible for the flight operations. We are also going to have in parallel with that pilot all the sensors and autonomy routines running in the background. So we'll be able to be collecting data on what that system is doing and comparing it to what the pilot is doing, and they'll be able to help each other. And as we gain more and more confidence as this progression happens, we'll be able to allocate more and more responsibilities to the system itself. But we're not going to wait for the magic day when all of a sudden, ooh, it's done. We're working on that progression in an organic way for product rollout.

Mr. WEBSTER. Okay. I yield back. Thank you all so much.

Chairman SMITH. Thank you, Mr. Webster.

The gentleman from South Carolina, Mr. Norman, is recognized for his questions.

Mr. NORMAN. Thank you all for being here. This is fascinating. It really is.

You know, in what you're doing, you're going to be facing—I guess dealing with a lot of regulatory agencies both on a federal level, state level, and local level. How do you navigate that? And this is really for anybody. When do you start the process? Because it looks like it would be a challenge.

Mr. THACKER. So I'm sure multiple people will have comments, but I think the key is you start early, you start now. We've already started. I think from a vehicle and operations standpoint, it's really important to get the whole FAA involved and to get a consistent outcome. We saw that with the drone as well when eventually the FAA basically put in place a structure that it was able to pull across all of the vehicle—the flight standards operation side and air traffic to help move that forward. We need to do that at the outset here to make sure that we have consistent regulation across those and we don't overburden any individual part of the system.

And then we need to be involved in communities. That's why with Uber, you know, we've had outreach to Los Angeles, to Dallas-Fort Worth areas where we can start the conversation, understand the community needs, make sure that we're reacting to those.

The last thing that we need is to have a patchwork of requirements across the country. We really need to have some consistency that allows us to execute in a scaled kind of way with the same vehicles, the same sort of operational models tailored locally with vertiport locations and things like that to manage noise, privacy, and other concerns but a consistent overall model from a regulatory standpoint, as well as from an operational standpoint.

Dr. SHIN. If I may build on Mr. Thacker's point, last point that this is a golden opportunity for the country that we can actually do this together in a very concerted and systematic manner. We don't have to repeat the same way that, as you mentioned, the patch jobs that we did 60, 70 years ago. So I think in the vehicle certification side, industry has been working really hard to get there, and I'm very optimistic that industry partners will get there. And from a government perspective, FAA and NASA have been working really well together to enable this new capability.

So I think, again, my point is this is one chance that we can actually design the system right and everybody, public and private, working together to come up with the robust system as best as we can design and from the get-go. So I think we're all working together. We're just representing various small segments of the community, but I can assure you that a lot of entities are working together in this field.

Dr. CLARKE. I would add that, you know, you can never start speaking to regulators early enough when it comes to aviation in the sense because you're always pushing the envelope and you're all bringing technology to the—for which they don't necessarily have expertise in-house. And so that's one of the foremost reasons for starting early.

I think in this case, you know, as I said earlier, I see a model for—a cable model for air-traffic control services just because it's just not practical in my view to have the FAA doing air-traffic management inside urban air sections. So I think there's going to be a new sense for certification, for certifying the companies and the entities that are doing the air-traffic management, which we haven't had to do before because that was all internal to the FAA. So I think there's going to be a need for regulations and processes for making sure that the folks who are actually managing the traffic are doing so in the way that you would like them to.

So that's one area which I think is slightly different than we've had before in aviation where, you know, it was just about the vehicles and the operators but not about air-traffic control. Now, we'll have to be able to do certification around it, and we'll have to make it nimble. You know, one of the things about aviation is we have very rigorous standards and implicitly—and in some cases explicitly—we get some release on liability.

Some of those standards are quite onerous and take a long time, and if you want not—if we don't want to throttle the growth of this industry, we'll have to figure out a model that is more nimble in regards to certification. And that's something that I think will require some legislation at some point.

Mr. NORMAN. I think that's where Congress comes in because we represent different constituencies, and we'll have a lot of concerns, both positive and negative. What about other countries? Technology-wise, it looks like that would be an area that you could collaborate with. Are you doing any of that with other nations?

Ms. DIETRICH. I will say that from a regulatory perspective we've had a lot of cooperation from other international civil aviation authorities, particularly EASA, so the new Part 23, Amendment 64, is harmonized with CS–23, Amendment 5, so that is very beneficial for the industry at large.

Mr. NORMAN. Yes, I wasn't talking about regulations. I was mainly thinking about technology-wise. I know as I get around my district a lot of the machinery comes from Germany, other countries. Is this something that you could possibly get with other nations on to look at?

Dr. SHIN. So NASA is a member of 26 member-states, an organization called International Forum for Aviation Research, so we—NASA was a founding member, along with the German aerospace agency some ten years ago when we formed this. The members are all government-backed or sponsored research organizations, so we're working to find out what the precompetitive but common technologies that we can raise the water level together and also harmonizing some of the technologies as standard possibly. So we're working with them and also we're working heavily with FAA, which represents the United States to the International Civil Aviation Organization, as Ms. Dietrich mentioned.

So a lot of work needs to be done, and I think you're pointing out very important points. Still a lot needs to be done, but I think the necessary part is working together.

Mr. NORMAN. Well, thank you so much. I yield back, Mr. Chairman.

Chairman SMITH. Thank you, Mr. Norman.

The gentleman from Florida, Mr. Dunn, is recognized for his questions.

Mr. DUNN. Thank you very much, Mr. Chairman, for having this meeting. I mean, really, thank you. This is so fun. This is catnip to aviation enthusiasts.

So like many of us, you know, I've spent hours poring over Popular Mechanics magazines, many of which were printed before anybody on the panel was born, pictures of flying cars and, you know, looking at that stuff, so it's exciting to actually have a chance to look at this in a—can I call this a professional manner?

My wife and sons, they fly. I'm not a pilot, but they all are, and we've flown into Oshkosh for fun a number of times. Oshkosh started yesterday, by the way. If I was there right now, could I be shopping for flying cars? Panel, anybody know?

Ms. DIETRICH. Terrafugia has an exhibit there.

Mr. DUNN. I could be shopping for a flying car today if I was in Oshkosh, Wisconsin. Let the record reflect that. That's just amazing, so cool. So I'm not going to ask any technical questions. I think you guys are smarter than me. You could solve all the FAA questions and, you know, the hybrid and everything and the balance weight. I think you're going to have to have autonomous because, let's face it, you know, flying planes is serious business.

But what I want to know from this very learned panel is, of all these examples of flying cars here, which one or two do you want the most? And I just want you to go right down the panel, tell me which one you think is the coolest. Start with you, Dr. Shin.

Dr. SHIN. As a government person, I shouldn't——

Mr. DUNN. See, everybody likes one. All right. What do you——

Dr. SHIN. But I—not generically, I like intermodal convenient way to do this, so whatever the designs may be and whatever the companies may be, it should be very—from my door at the home and——

Mr. DUNN. Okay. So all the way, door-to-door. Okay. That's great. Sort of The Jetsons thing, right? Did you like the Aston Martin version? That's pretty cool, huh?

Dr. SHIN. I'm a little bit of a car nut, so that was really fancy that they put on.

Mr. DUNN. Dr. Clarke?

Dr. CLARKE. So I have mixed minds here because, as Ms. Dietrich will tell you, I used to teach her husband when he was an undergrad. And, as Dr. Allison will tell you, my—one of my Ph.D. students is his lead analyst and optimizer and modeler, so I have interest in both solutions.

I got to tell you, Mr. Chairman, I—and other members, I am a James Bond fan——

Mr. DUNN. I knew it.

Dr. CLARKE. —and I'm also a Jetsons fan, so I actually like the idea of being able to leave your house and basically be able to go from door-to-door. I mean—

Mr. DUNN. Door-to-door.

Dr. CLARKE. —door-to-door is the ultimate, right? That's what we care about.

Mr. DUNN. That's it. So—well, Mr. Allison, do you care to respond?

Dr. ALLISON. So we have five amazing vehicle partners with Uber Elevate, and I'm very excited to see all five of those vehicles fly sometime soon.

Mr. DUNN. So you don't have one that you would maybe want to tuck in the garage first?

Dr. ALLISON. I'm very excited to see all of them fly, but Mr. Thacker's vehicle from Bell will also be one of the great ones.

Mr. DUNN. Outstanding.

Mr. THACKER. I'm obviously biased towards the Bell solution, and I do believe that the air taxi will bring a sweeping change to how we move about cities, and I'm excited about that one because I think it will be here sooner than the door-to-door solution, and it's something that all of us will be able to take part in. So—and if you'd like to experience that, we have a virtual experience that I welcome any of you to come take when you get the chance.

Mr. DUNN. Will you share the information with the staff so they can get it to us?

Mr. THACKER. Absolutely.

Mr. DUNN. Thank you. So that will be very important. So, please——

Ms. DIETRICH. Well, I have——

Mr. DUNN. —solve my dilemma. Pick one for me.

Ms. DIETRICH. I was one of the founders of Terrafugia specifically because I wanted a Transition, so fortunately, next year, I should be able to get to really fly a Transition again and use that vehicle a little bit. It's not quite the urban mobility that we're talking about, but to be able to fly and drive the same vehicle, I'm very excited about that. Building and flying a vehicle that I helped create was one of my career goals.

Mr. DUNN. I agree. Okay. I have a very large district, and I think you've just solved one of the problems I have here. Now, which one of these should I choose to commute across a district that's 350 miles long, eight hours of driving on the interstate, more if you take the back roads, lots of back roads, lots of farms?

Ms. DIETRICH. Well, I would recommend a TF–2 for you, and that——

Mr. DUNN. TF–2. Write this down.

Ms. DIETRICH. The 200-mile minimum range with a ground vehicle integration so you'll be able to get the back roads and the vertical flight component.

Mr. DUNN. What options should I order?

Ms. DIETRICH. We can talk about customization.

Mr. DUNN. Mr. Chairman, let me say thank you again for having this meeting. It's been one of the high points of my time in Congress. I yield back.

Chairman SMITH. Thank you, Mr. Dunn. I think she'll offer you a discount, but that's another story.

Now, Ms. Bonamici—before I recognize the gentlewoman from Oregon, did you come for the free flying car or did you come—we only have two left, so we're getting to the end here.

Ms. BONAMICI. I——

Chairman SMITH. The gentlewoman——

Ms. BONAMICI. I wish I could say yes, Mr. Chairman.

Chairman SMITH. The gentlewoman is recognized.

Ms. BONAMICI. Thank you, Mr. Chairman. And my apologies for not being here for your testimony. I was in another committee, which is not nearly as much fun. No one was laughing there.

But thank you so much for your testimony, which I have looked through. And I—you know, I frequently hear from my constituents out in northwest Oregon. They complain to us about everything but including traffic. And I hear from communities and businesses and individuals about the need to invest in infrastructure and how we put people back to work and how do we move people, how do we move goods. And my vision for infrastructure isn't just limited to roads and bridges. We need to invest in new transportation policy, new transportation infrastructure from high-speed rail to bicycle pedestrian pathways, and I'm interested in hearing from you about expanding this vision to include urban air mobility. I'm sure it's something that would be quite popular in the Pacific Northwest.

One of the things I want to get to also is that I think the workforce in this field is going to need to be innovative and entrepreneurial, and I can tell that from your testimony, which I read. Those characteristics require creative and critical thinking. I also work on a lot of education issues, and I'm the Co-Chair and the founder of the bipartisan STEAM Caucus with Representative Stefanik from New York where we're working on ways that we can educate people who are creative and innovative through integration of arts and design in traditional STEM fields.

I want to ask Dr. Clarke, what steps is the aviation research community making to make sure that students get the well-rounded education for the urban air mobility industry, and how—especially how those efforts might change as technology develops? How are you educating, you know, creative critical thinkers?

Dr. CLARKE. Thank you for the question, Congresswoman. One of the things that we're doing, first of all, is a lot of the universities, including my own, have been changing the curriculum and updating the curriculum over time to include more what would—I would say holistic topics. And the second thing is that we've also been trying to introduce a lot more the idea of innovation and—at the undergraduate level to try to—I was mentioning earlier before you stepped in that I've never seen the level of excitement that it is now amongst aerospace students in particular and the fact that people are out there starting companies or are coming up with ideas and trying to look for investors around new types of vehicles. So from the educational perspective moving beyond just, you know, engineering, science and the "here's an equation, here's the solution to the equation and that's the end," it's thinking about the economic implications, thinking about the regulatory implications, bringing those in. And to credit ABET, which is the accreditation agency, has been pushing that for the last decade or more.

And then—but there's definitely an emphasis—I know at Georgia Tech we are trying to make sure that every graduate of Georgia Tech has some thought and has given some thought and has done something around innovation and basically entrepreneurship, which I think goes towards, again, generating jobs and opportunities in the United States.

Ms. BONAMICI. So that's great to hear. We've had many conversations about how do we educate people today for the jobs that we can't imagine?

Dr. CLARKE. Right, right.

Ms. BONAMICI. In your testimony you talk about, all of you, your version for urban air mobility will eventually lead to autonomous vehicles hovering just hundreds of feet above us. I remember in Portland when they built an aerial tram to get from one part of the medical school to another and people who lived underneath it panicked, and of course with the UAV conversation. Can you elaborate on what steps you are taking to protect the privacy of consumers and individuals affected in the surrounding flight path, whoever wants to weigh in on that?

Dr. CLARKE. Well, I mean, for me I think the steps that need to be taken are pretty straightforward. We don't understand that trade-off between utility and privacy that is inherent in every one of us. I've spent time in the Netherlands, and they have great open windows and—in big—in cities in the Netherlands, and that's when I realized that privacy is a different thing than anonymity, so that's one thing that we have to really understand.

And then the second is what's that trade-off that—what are people willing to give up for the utility? That's another thing. I mean, people give up lots of information on their cell phones and stuff because they find it useful, and so that's something that needs to be understood. Once we have that, we can actually start doing modeling and optimizing where we put vertiports, what kind of trajectories need to be put in place, so it's a three-step process, figuring out what people—what that trade-off is, figuring out the models to model it and then optimizing.

Ms. BONAMICI. In the remaining few seconds, anybody want to weigh in on changes we might need to make as we're considering infrastructure investments?

Dr. ALLISON. So, thank you, Congresswoman, for the question. We think about this very much as multimodal solutions, and so Uber is interested in different modes of transportation and recently introducing bikes on our app. We see Elevate the same way, that this is a type of transit system that will integrate into other things, and it introduces one key feature that is not available right now in most of the transportation system, which is that the cost of building out this type of infrastructure doesn't scale by the—per foot of road you lay or track you lay or tunnel you dig perhaps. It scales with the nodes that you put in, and so it's a nodal-scaling network. So the cost-scaling is very different than the way we think about transportation system and cost-scaling right now, and we think that will be a key feature down the road, so to speak, of how this type of a system integrates into the rest of the transportation system writ large.

Ms. BONAMICI. Thank you. I yield back, Mr. Chairman.

Chairman SMITH. Thank you, Ms. Bonamici.

This concludes our hearing today, and I just want to thank all of our expert witnesses for being here and for their testimony. Obviously, this is inspirational and soon to be—we hope—real-time and realistic.

And we're going to do something we haven't done before, which is to make a presentation to you all. So if you will stay close to the table, here's the beginning of what we're going to present you. And let me say if you can't take it with you—and that would be totally understandable—we'll figure out a way to get it to you one way or the other, or maybe you can figure that out, too.

So I'll come around and hand you the package with the flying car. By the way, the flying car has its wings out as you get it, but the wings actually collapse and fold vertically against the body of the car, and you simply push one button and the wings come out horizontal, and you're off the ground in 15 feet. You can't beat it.

I do not get a commission. Actually, I don't know who makes them exactly.

Dr. CLARKE. Mr. Chairman, I would—Mr. Chairman, you have now introduced a problem in my household because I have twin boys but——

Chairman SMITH. Oh, they'll love it.

Let's see. The record will remain open for two weeks for additional written comments and written questions from members.

And we stand adjourned.

[Whereupon, at 11:54 a.m., the Committee was adjourned.]

Appendix I

Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Responses by Dr. Jaiwon Shin

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"Urban Air Mobility – Are Flying Cars Ready for Take-Off?"

Dr. Jaiwon Shin, Associate Administrator, Aeronautics and Research Mission Directorate, NASA

Questions submitted by Chairman Lamar Smith, House Committee on Science, Space, and Technology

1. There are a series of challenges that need to be overcome before UAM can come to fruition. In your opinion, what are the top two most significant technology and regulatory challenges that need to be overcome to make UAM a reality?

   Answer: Urban air mobility (UAM) system-level considerations require many individual technologies to coalesce. From a technical perspective, this includes technologies to provide safe and efficient air traffic management (ATM) for a large number of vehicles, and to find ways to ensure safety of passengers and people on the ground in contingency situations. Challenges around developing, testing, and certifying the necessary ATM technologies and contingency management technologies will both require levels of automation that do not have a precedent for certification and also operational approval. From the regulatory perspective, the challenges will be developing approaches and sufficient data to get these novel vehicles' configurations certified (i.e., assuring that they are safe) and obtaining an approval for operations in and around dense urban areas. While NASA is not heavily involved in the area of cybersecurity, given the nature of UAM this could be a challenging area. While the system needs to be interconnected and have the ability to easily share data among the users, it must be secure from outside tampering. The FAA and other agencies are working on the cybersecurity issue. As the UAM community integrates IT into the systems, improving the interconnectivity of the parts, this will become more and more of an issue to ensure the IT systems can be integrated into a community wide ecosystem. There will also likely be significant regulatory challenges in developing noise standards and ensuring the public accepts noise profiles created by UAM activities.

2. What roles will be played by the private and public (federal, state, local) sector to advance UAM transportation? How will the various participants in the UAM community collaborate on their roles to address issues as disparate as safety, environment, cybersecurity, zoning etc.?

   Answer: This is a nascent industry, and roles are still being developed and assessed. Industry is working diligently to bring first generation vehicles to market. Federal agencies need to develop appropriate regulations, policies and processes for vehicle and operational certification, and also development, deployment and/or oversight of essential ATM management systems (i.e. UTM). The public and private sectors will be required to work together to ensure the entire system meets the safety expectations of the flying public. This will include many topics such as significant technology development, operational R&D, standards development, Verification &Validation (V&V) needs, and cybersecurity requirements. From the local perspective, issues such as zoning, noise, privacy, .land rights, and other considerations will need to be addressed to enable the full UAM vision.

The various participants are currently collaborating informally through conferences, workshops, forums, standards bodies, and business-developed consortiums. In the future it is envisioned that robust public-private partnerships may contribute to fully coordinate and approve UAM operations.

3. There has been extensive research conducted in battery technology aimed at surface transportation. Are the battery needs of aviation different from surface transportation, and would it be beneficial to consider these issues in research programs?

   Answer: Battery needs for aviation are quite different, and more challenging, than requirements for surface transportation. For example, batteries for aviation propulsion systems need to deliver higher power at significantly lower weight. These systems must also include redundancies and other unique safety features not needed in surface transportation. Requirements for air vehicle weight limitations, life cycles, power needs, operating temperatures, and safety/reliability are all significantly different than surface transportation needs. While NASA ARMD has strong research efforts underway in UAM, electric propulsion and hybrid- electric propulsion, NASA believes it is most appropriate to leverage advances in battery technologies through research being conducted by other entities in government, academia and industry, as opposed to initiating our own research in this field.

4. It is a central mission of the National Institute of Standards and Technology (NIST) to develop standards in just about everything. What role has NIST played thus far in the UAM discussion? As the technology progresses and discussions turn to standardizing various aspects of the UAM concept, how might an agency like NIST contribute?

   Answer: NASA has been regularly coordinating with NIST through both the Cyber Physical Systems (CPS) Interagency Work Group (IWG) and through the Global Smart Cities Initiative. Key technical interchanges have revolved around frameworks and standards for supporting autonomous systems services that would help enable intelligent vertiports and autonomous, on-demand vehicles and systems. NASA may not be fully aware of the entire set of NIST interactions, but many standards groups will be required to develop UAM standards. NIST will likely play a significant role in this process.

5. Safety concerns relative to VTOLs fall under two general buckets: safety of passengers on the vehicle and safety of the public outside the vehicle in the event of a catastrophe. How might issues of liability be handled when something goes wrong and people perish?

   Answer: This issue is outside of NASA's scope and mission.

6. As our efforts to develop UAM progresses, where do we expect to see delays – in the development of technology, or in the ability of the public sector (federal, state, local governments) to keep up with innovation by implementing the relevant polices and regulations in a timely manner?

   Answer: It is difficult to characterize the speed of likely progress in evolution of UAM due to the nascent nature of the UAM industry. While technologies to enable UAM are converging, there are many individual technology and integration issues that are not yet solved including vehicle configuration, automation, batteries, operational issues and systems integration issues. These types of challenges are typical to complex technology development and systems integration. There are similar significant policy and regulatory challenges to adoption of UAM. It is difficult to predict how quickly these challenges will be overcome. However, a successful UAM industry will require advances in all of these areas in order for a safe system to be accepted by the broader public.

7. Besides NASA and FAA, what other federal agencies have a role to play in the design, development or rollout of VTOLs and the UAM system, and what are their roles?

   Answer: Private industry around the world is making heavy investment in the design and development of electric VTOLs with diverse design concepts. Therefore, NASA believes its role should be leading the community by addressing system-wide issues such as safety and community noise. NASA is also working with the FAA to develop efficient and effective ways of certifying these new air vehicles. Beyond the vehicle development, NASA and FAA are collaborating to develop a new way to manage high-volume traffic at low altitude. In addition to the air vehicle and air traffic management development, many federal, state and local governments would have important roles to address other key areas such as cybersecurity, infrastructure for vertiports and charging stations, power grid management, and accurate aviation weather service.

8. With regard to developing VTOLs and the UAM system, is there any international coordination or collaboration, either with other governments or with companies registered in other nations? How do we walk the fine line between protecting sensitive information or trade secrets, yet still work with foreign counterparts to learn from and teach each other?

Answer: As a founding member of The International Forum of Aviation Research (IFAR), NASA is working with IFAR-represented countries on pre-competitive and common technologies and challenges that member governments can work together to "raise the water level for all." IFAR aims to connect research organizations worldwide, to enable the information exchange and communication on aviation research activities and to develop among its members a shared understanding on challenges faced by the global aviation research community. IFAR members are government-funded national R&D organizations conducting aeronautics research, or universities representing the countries that do not have national aeronautics laboratories. By focusing on. pre-competitive and common technologies, NASA continues to walk the fine line between protecting sensitive information including trade secrets, while working with members of the IFAR community. In general, NASA works with the international community in areas such as information related to setting international standards and recommended practices for aviation safety and cross-border operations, but not in areas such as research into design tools or specific technologies that may have a competitive impact. NASA has engaged with IFAR members on some limited aspects of UTM, and similarly is considering opportunities for discussions with IFAR members about UAM. NASA Aeronautics typically does not work directly with non-U.S. companies; any such partnerships would be considered on a case-by-case basis in accordance with NASA policies.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"Urban Air Mobility – Are Flying Cars Ready for Take-Off?"

Dr. Jaiwon Shin, Associate Administrator, Aeronautics and Research Mission Directorate, NASA

Questions submitted by Ranking Member Eddie Bernice Johnson, House Committee on Science, Space, and Technology

1. In his prepared opening statement, Dr. Clarke stated that the four most urgent and most difficult research projects identified by the 2014 National Academies Panel on autonomy are relevant to the realization of UAM. He also stated that while NASA had started research in each of these areas, progress had been slow and needed to be accelerated.

    a. Do you agree with his characterization of NASA's level of activity?

    Answer: We appreciate Dr. Clarke's contributions to the publication of the National Academies Autonomy study, which is a service to the whole community. NASA believes that we have a unique role making high impact contributions to the emerging urban air mobility (UAM) community by addressing system-wide barriers. One such example is NASA's focus on research for developing technologies, data, and methods for establishing new safety standards and certification methods. If these barriers are not addressed, there will be no realization of a UAM market of any kind. Industry, on its own, is making significant investments for vehicle designs and developments with various approaches to more and eventually fully autonomous operations of UAM vehicles. NASA and industry will continue to work together, leveraging each other's investment and expertise without duplicating efforts to advance the state of autonomy research. NASA develops its research priorities and deliverables in close coordination with the relevant safety, operational, and regulatory components of the Federal Aviation Administration. Because NASA is not a regulatory agency, accelerating NASA research in an uncoordinated manner will not effectively reduce the barriers to realizing UAM.

    b. If you agree with the need for increased activity, how and when could NASA begin to accelerate its efforts? If you do not agree, why not?

    Answer: NASA agrees with the need for increasing activity in autonomy research across the aviation community, including both vehicles and air traffic management, and is adjusting our portfolio accordingly. NASA introduced an autonomy thrust in our 2015 Strategic Implementation Plan, but had been working on autonomy related activities for many years prior. Specifically, NASA's

Unmanned Aircraft Systems (UAS) Integration in the National Airspace (NAS) project has been working the autonomy thrust providing significant benefit to the UAS community through developing broadly applicable "detect and avoid" and "command and control" technologies. NASA has also led a national effort in development of a UAS Traffic Management (UTM) technology that will be leveraged to automate air traffic management of UAS in airspace that is not typically required to be actively managed by the FAA.

While the levels of autonomy required for introduction of Urban Air Mobility (UAM) may be minimal, NASA does agree that autonomous technologies are essential to enable the full benefit of UAM. In the past two years, NASA has increased the focus on autonomy research. NASA is in the planning phase for a focused autonomy project designed to provide even more benefit towards UAM. NASA is currently working with a broad industry community defining additional autonomy research efforts as a new set of non-traditional aviation companies (e.g. google, amazon, intel, etc.) with significant experience in autonomy, but minimal experience in aviation, progresses towards implementation of aviation products.

The envisioned use cases of both UAM and low altitude UAS need the vehicles to operate in the same airspace as current manned and commercial aviation. NASA's UTM and Air Traffic Management-Exploration (ATM-X) projects will research how to enable the seamless, safe and efficient integration of all users of the airspace. The federated air traffic management architecture of the UTM project will be leveraged to establish a federated future air transportation management system that is scalable from the current manned daily operations of tens of thousands of vehicles to the envisioned manned or unmanned millions of daily vehicle operations through introduction of UAM and low-altitude UAS. NASA's research will seek to enable equitable access to the airspace for all users, vehicles, and missions by developing and demonstrating a new service-based paradigm leveraging UTM principles using a build and test approach to provide:

- Seamless access to the airspace for users and missions—both on-demand (UAM, UAS) and scheduled (supersonic, ultra-high altitude, and space);
- Scalability for increased demand across users and missions;
- Flexibility whenever possible and structure only when necessary;
- Collaboration through integrated information exchange;
- Resilience to uncertainty, degradation, and disruptions; and
- Increased availability and use of user and third-party services.

Furthermore, NASA's System-Wide Safety (SWS) project will enable data-driven, prognostic in-time system-wide safety for diverse and more highly automated airspace operations. The project's goals are to explore, discover, and understand the impact on safety of growing complexity introduced by modernization aimed at improving the efficiency of flight, the access to airspace, and/or the expansion of services provided by air vehicles. The SWS project will:

- Develop and demonstrate integrated risk assessment capabilities to monitor terminal area operations based on data analytics and predictive models;
- Develop and demonstrate integrated dependable monitoring, assessment, and mitigation capabilities for safety-critical risks to low-altitude urban beyond visual line-of-sight (BVLOS) small UAS (sUAS) operations; and
- Develop and demonstrate cost-efficient Validation and Verification (V&V) tools, methods, and guidance that provide justifiable confidence in safety claims for designs of complex, safety critical Air Traffic Management (ATM) and avionics systems.

Many players in this emerging UAM industry think that vertical lift vehicle capability combined with autonomy are key to realizing the potential business case of new missions and new markets. NASA is proactively examining what and how our strong vertical lift expertise can make timely and compelling impact to major barriers to the UAM market such as noise and safety.

c. Would this UAM research require additional funding? If so, when could we expect to see a budget request?

Answer: NASA is engaging with a broad range of stakeholders to assess the appropriate levels and areas of research where NASA can have the greatest impact in the emerging UAM market. This emerging market presents a significant potential for the U.S. economy and the government must work together with industry to ensure U.S. global leadership. NASA envisions maintaining an important role in supporting the UAM sector. NASA research objectives and associated resource requirements are documented in the President's annual budget requests.

2. Last year, NASA contracted with two consulting firms to conduct a market analysis of UAM to help the agency decide how to deploy resources and develop an appropriate research agenda. Is that analysis complete and if so, to what extent has NASA incorporated those results into its UAM research strategy?

Answer: The UAM market studies and analysis that NASA funded are not yet complete, however they are being factored in to our decision-making processes. We have formed a UAM Coordination and Assessment Team (UCAT) to supply cohesive, well-coordinated thinking across various ARMD projects that need to contribute to UAM research. The two market studies results are used with the coordinated efforts by UCAT. We have disseminated preliminary study results to researchers and project managers in relevant projects who are using them as guidance. NASA's UAM strategy efforts are using these inputs to help determine and prioritize critical barriers that need to be addressed by NASA and the broader community. NASA has also leveraged these studies to document critical operational concepts that our research portfolio will help enable, and to understand and begin coordination with the entire ecosystem of UAM-related partners (e.g., other government agencies, appropriate standards orgs, infrastructure developers, local regulators, Smart Cities, etc.).

3. In your prepared statement, you state that communities will not accept noise that significantly exceeds background noise levels and that crafting acceptable noise standards will require understanding community response to different noise signatures.

    a. Can you suggest a way by which aircraft noise reduction technology and operational mitigation procedures can be evaluated by communities before UAM operations are initiated?

        Answer: NASA ARMD is currently focusing on research and is drafting a Technical Challenge area that targets the development of methods and tools to assess the noise impact on the community caused by operations of a UAM fleet. As part of this work, trajectory (flight path) optimization will be evaluated as a means to mitigate the noise from these vehicles as perceived on the ground. The methodology and resulting tool are expected to be used by operators, municipal planners, and regulatory agencies when they are completed. The tool will be based on modifications to the commonly used FAA Aviation Environmental Design Tool (AEDT). Additionally, NASA is considering opportunities for organizing flight demonstrations to evaluate noise impacts, in which industry could "try out" their vehicles and assess their performance in a relevant environment.

    b. How can better modeling and simulation tools enhance the ability to predict the noise level from different concepts?

        Answer: NASA is currently considering a Technical Challenge research area that will improve the high-fidelity modeling of multi-rotor, variable rpm control UAM configurations. The focus is to develop an essential capability to model complex and unusual configurations in a way that accurately calculates the noise from the multiple rotating systems, and the noise generated by the interaction with the airframe that is generally missing from current modeling tools.

        There is a wide range of UAM vehicle concepts. Noise generation mechanisms will likely differ from one to another. Experimentally validated and robust modeling and simulation tools will allow vehicle manufacturers to develop effective noise mitigation technology, including operations. Further, tools that are applicable across a wide range of vehicle architectures will allow trade studies to be performed with reduced uncertainty.

4. Over the last several months this Committee has been examining the state of artificial intelligence and machine learning technologies and their potential benefits for many industries. How will machine learning affect development of UAM? What machine learning and data analysis tools is NASA researching that relate to UAM?

   Answer: NASA believes that machine learning can have a dramatic influence on the long-term success of UAM. While machine learning is likely not a requirement for the initial and intermediate timeframes for UAM, there is potential for a dramatic impact on the efficiency of the system as the industry reaches its mature state. The possibility of using machine learning to understand and predict localized weather in urban environments could play a critical role in UAM. As machine learning matures, it may also be able to handle critical functions that pilots today deal with intuitively, such as responding to an off-nominal scenario and then efficiently resolving the problem and optimizing the approach to return back to the original mission for the system.

5. According to the FAA, there are approximately 5,000 aircraft in the sky at any time and more than 42,000 flights daily handled by the FAA. I understand that UAM vehicles will be operating at altitudes far below commercial aircraft.

   a. How would integrating commercial traffic management and UAM traffic management make air travel safer?

      Answer: Critical elements of aviation safety are situational awareness and separation assurance. A safe National Airspace System must consider all elements, and all aircraft, in order to ensure a truly safe system. The United States' current air traffic management (ATM) system is the safest in the world, but will require coordination and integration with an Unmanned aircraft system Traffic Management (UTM) system in situations where small UAS (sUAS) and urban passenger transport vehicles must interface. NASA and the FAA are currently working the integration of current ATM and future UTM systems through programs such as the FAA's Low Altitude Authorization and Notification Capability (LAANC). The UTM allows for multiple operators to share operational intent with each other through predefined data exchange protocols. Such a "share and care" environment gives complete situational awareness to all sUAS operators so that each sUAS operator can plan, schedule, fly, and track their operation in a safe manner without interfering with other operators. Further, the FAA can add real-time restrictions for safety and security reasons.

The envisioned use cases of both Urban Air Mobility (UAM) and low-altitude sUAS require the vehicles to operate in the same airspace as current manned and commercial aviation. NASA's UTM and Air Traffic Management-Exploration (ATM-X) projects are researching how to enable seamless, safe and efficient integration of all users of the airspace. The federated air traffic management architecture of the UTM project will be leveraged to establish a federated future air transportation management system that is scalable from the current manned daily operations of tens-of-thousands vehicles, to the envisioned manned and unmanned daily operations of millions of vehicles after the introduction of UAM and low-altitude UAS. NASA seeks to enable equitable access to the airspace for all users, vehicles, and missions by developing and demonstrating a new service-based paradigm leveraging UTM principles using the build-and-test approach to provide:

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- Develop and demonstrate cost-efficient Validation and Verification (V&V) tools, methods, and guidance that provide justifiable confidence in safety claims for designs of complex safety critical Air Traffic Management (ATM) and avionics systems.

b. Can you expand on NASA's research related to detect and avoid and communication requirements for unmanned aircraft systems and its potential applicability to UAM vehicles?

Answer: NASA has been working Detect and Avoid (DAA) and Command and Control (C2) through both the UAS Integration in the NAS (UAS-NAS) and UAS Traffic Management (UTM) Projects. From the UAS-NAS perspective, research has been baselined as part of consensus standards developed in partnership with the Radio Technical Commission for Aeronautics (RTCA). From the UTM perspective, utilization of DAA and C2 technologies have been tested as part of the UTM national campaign demonstrations, UTM Pilot Program (UPP), and Integration Pilot Program (IPP). While all variants of these technologies are relevant to UAM, all also have additional research that needs to be conducted to understand direct applicability to the infant UAM concepts of operations. For instance, sensors hosted on-board UAS are designed to specific performance capabilities to detect aircraft specific to that UAS's operating environment. A scaled urban environment would require aircraft to operate in significantly more dense operating environments. While there are no specific limitations of the technology that would make the technology irrelevant, many of the design parameters would need to be modified, at minimum, to enable the same types of operation in dense urban environments transporting passengers.

6. NASA's Aeronautics Research Mission Directorate has a critical role in assisting industry in their development of UAM vehicles and operations. NASA provides research results, tools and guidance to its industry partners for safety verification and validation activities. Unique facilities are available to partners under Space Act Agreements. What additional facilities, infrastructure, staff or tools are necessary for NASA to maintain U.S. leadership in UAM research?

   Answer: NASA's workforce, facilities and infrastructure have long been critical assets to the nation. As currently envisioned, UAM presents significant new challenges to the aviation industry, and NASA has already been exploring existing and new capabilities necessary to enable to the short and long-term UAM vision. Under the UAS integration in the NAS (UAS-NAS) and UAS Traffic Management (UTM) projects, NASA has spent significant time and money developing state-of-the-art capabilities for research on air traffic management, fast-time simulation, and other modeling and simulation capabilities. There are also several critical safety related tools developed by NASA that are essential to ensuring the nation is providing a transportation system that is acceptable to the public, while also providing the ability to ensure the system is becoming increasingly safe. These tools and capabilities will need to be further developed to address the significant challenges relevant to optimizing high-density urban operations.

NASA ground test infrastructure such as wind tunnels and acoustic facilities can be used to test and assess UAM concepts and technologies. These capabilities will need to be assessed to identify whether they need to be modified to meet the needs of new and novel UAM vehicle configurations.

NASA is planning to leverage restricted airspace at the NASA Armstrong Flight Research Center and adjacent Edwards Air Force Base for initial UAM flight testing, but NASA facilities will not likely satisfy the broader UAM community testing needs in the coming decade. Appropriate test sites and ranges beyond those of NASA will be critical to the enabling of the UAM industry. The FAA UAS test sites have been instrumental in progressing UAS integration, but must be accepted by industry and developed as part of a broader UAM-wide strategy to maximize their benefit. UAM proving grounds will need to be developed for both rural and urban environments, have robust communication environments, incorporate significant instrumentation upgrades, and many other costly developmental considerations.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"Urban Air Mobility – Are Flying Cars Ready for Take-Off?"

Dr. Jaiwon Shin, Associate Administrator, Aeronautics and Research Mission Directorate, NASA

Questions submitted by Representative Jacky Rosen, House Committee on Science, Space, and Technology

1. As the urban air mobility (UAM) industry continues to develop vehicles, it is imperative that we begin addressing safety and management issues. Congress, FAA, NASA, local jurisdictions, and industry will need to work together to answer a multitude of questions, including: who will police the skies or respond to potential accidents? Who will be liable? How will jurisdiction of physical airspace be divided?

   Answer: These questions are outside of NASA's scope and mission, and are best addressed by other agencies.

   a. Can you address these questions and offer your thoughts as to how we tackle them?

      Answer: These questions are outside of NASA's scope and mission, and are best addressed by other agencies.

   b. The FAA has "No Drone Zones" throughout the country and over some U.S. military facilities and airports – restricting unmanned aircraft flight. I represent a Congressional District that borders Las Vegas' McCarran International Airport, one of the busiest airports in the country. We are also less than twenty miles from Nellis Air Force Base and just over fifty miles from the Nevada Test and Training Range, which provides the largest air and ground military training space in the contiguous U.S., without interference from commercial aircraft. What will happen if UAM vehicles with passengers fly into this restricted airspace?

      Answer: These questions are outside of NASA's scope and mission, and are best addressed by other agencies.

2. I know that unmanned aircraft systems traffic management, or UTM, is something NASA has been working on quite extensively.

   a. What can you tell us about the progress or expected results of NASA's research with UTM and UAM?

      Answer: The Unmanned aircraft system Traffic Management (UTM) project established a set of four Technical Capability Level (TCL) demonstrations, each increasing its level of maturity, technical capability, and complexity of operations. To date, NASA has completed TCLs 1 through 3.

TCL1 demonstrated the concept for management of airspace in lower-risk environments of uninhabited areas and multiple visual line-of-sight (VLOS) unmanned aircraft systems (UAS) operations. The demonstrations and flight trials were conducted in Crows Landing, CA, and six FAA UAS test sites with 19 industry partners in August 2015 and May 2016. The results validated a cloud-based service oriented architecture and defined requirements for enabling low-altitude UAS operations in unpopulated areas with VLOS operations.

TCL2 demonstrated the complexity of multiple beyond visual line-of-sight (BVLOS) UAS operations in lower risk environments of sparsely populated areas. The demonstrations and flight trials were conducted at the Reno-Stead airport, NV and six FAA UAS test sites with 42 industry partners in October 2016 and June 2017. The results demonstrated information sharing between operators and supplemental service providers, and established the federated third party service model.

TCL3 demonstrated technology enablers to address challenges presented by multiple BVLOS UAS operations over moderately populated areas and near airports. The demonstrations and flight trials were conducted at six FAA UAS test sites with 34 industry participants during March-June 2018. The results demonstrated enabling technologies for detect and avoid, communication and navigation, and data exchange between service providers.

TCL4 is currently in the planning stage to demonstrate complex operations in highly populated areas and large-scale contingency management during the summer of 2019. The UAS test sites and industry participants are to be determined upon evaluation of the solicitation proposals. The results will determine understanding of the UTM operational concept, vehicle technologies, and data exchanges for nominal and contingency operations to safely fly in the vicinity of large structures and highly populated areas.

NASA and FAA have efficiently and closely engaged through the NASA/FAA UTM Research Transition Team (RTT) in defining the NASA-needed algorithms, research platforms, prototypes, and data that NASA must deliver to the FAA to enable their development of requirements, standards, and certifications. The UTM RTT through its four working groups -- Concepts and Use Cases, Data and Information Exchange, Sense and Avoid, and Communications and Navigation -- is enabling the coordination of NASA research with the needs and requirements of FAA Air Traffic Organization (ATO), NextGen (ANG), and Aviation Safety (AVS) organizations.

b. How would integrating commercial traffic management and UAM traffic management make air travel safer?

Answer: Critical elements of aviation safety are situational awareness and separation assurance. A safe National Airspace System must consider all elements, and all aircraft, in order to ensure a truly safe system. The United States' current air traffic management (ATM) system is the safest in the world, but will require coordination and integration with a Unmanned aircraft system Traffic Management (UTM) system in situations where small UAS (sUAS) and urban passenger transport vehicles must interface. NASA and the FAA are currently working the integration of current ATM and future UTM systems through programs such as the FAA's Low Altitude Authorization and Notification Capability (LAANC). The UTM allows for multiple operators to share operational intent with each other through predefined data exchange protocols. Such a "share and care" environment gives complete situational awareness to all sUAS operators so that each sUAS operator can plan, schedule, fly, and track their operation in a safe manner without interfering with other operators. Further, the FAA can add real-time restrictions for safety and security reasons.

The envisioned use cases of both Urban Air Mobility (UAM) and low-altitude sUAS require the vehicles to operate in the same airspace as current manned and commercial aviation. NASA's UTM and Air Traffic Management-Exploration (ATM-X) projects are researching how to enable seamless, safe and efficient integration of all users of the airspace. The federated air traffic management architecture of the UTM project will be leveraged to establish a federated future air transportation management system that is scalable from the current manned daily operations of tens of thousands vehicles, to the envisioned manned and unmanned daily operations of millions of vehicles after the introduction of UAM and low-altitude UAS. NASA seeks to enable equitable access to the airspace for all users, vehicles, and missions by developing and demonstrating a new service-based paradigm leveraging UTM principles using the build-and-test approach to provide:

- Seamless access to the airspace for users and missions — both on-demand (UAM, UAS) and scheduled (supersonic, ultra-high altitude, and space);
- Scalability for increased demand across users and missions;
- Flexibility whenever possible and structure only when necessary;
- Collaboration through integrated information exchange;
- Resilience to uncertainty, degradation, and disruptions; and

- Increased availability and use of user and third-party services.

Furthermore, NASA's System-Wide Safety (SWS) project will enable data-driven, prognostic in-time system-wide safety for diverse and more highly automated airspace operations. The project's goals are to explore, discover, and understand the impact on safety of growing complexity introduced by modernization aimed at improving the efficiency of flight, the access to airspace, and/or the expansion of services provided by air vehicles. The SWS project will:

- Develop and demonstrate integrated risk assessment capabilities to monitor terminal area operations based on data analytics and predictive models;
- Develop and demonstrate integrated dependable monitoring, assessment, and mitigation capabilities for safety-critical risks to low-altitude urban beyond visual line-of-sight (BVLOS) sUAS operations; and
- Develop and demonstrate cost-efficient Validation and Verification (V&V) tools, methods, and guidance that provide justifiable confidence in safety claims for designs of complex safety critical Air Traffic Management (ATM) and avionics systems.

Responses by Dr. John-Paul Clarke

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"Urban Air Mobility – Are Flying Cars Ready for Take-Off?"

Dr. John-Paul Clarke, College of Engineering Dean's Professor, Georgia Institute of Technology; Co-Chair, 2014 National Research Council Committee on Autonomy Research for Civil Aviation

Questions submitted by Chairman Lamar Smith, House Committee on Science, Space, and Technology

1. There are a series of challenges that need to be overcome before UAM can come to fruition. In your opinion, what are the top two most significant technology and regulatory challenges that need to be overcome to make UAM a reality?

   Answer: I believe that: (1) greater flight vehicle automation and autonomy; and (2) an air traffic management system with an open architecture and automated multilateral conflict detection and resolution are the top two most significant technology challenges that must be overcome before UAM can come to full fruition.

   Greater flight vehicle automation and autonomy will be critical to achieving optimal human-machine teaming, where the role of humans and machines (in this case automation on board flight vehicles) are optimized based on their individual and collective capabilities, thereby achieving safe and efficient (economic and environmental) operations. As stated in both my written and oral testimony, the economics of UAM do not support the employment of human operators that are trained, and thus compensated, at the same rates as commercial pilots. Thus, there will be a greater role for automation than is currently the case in commercial or general aviation. Furthermore, because rapid decision-making and action is critical in flight vehicles that operate in close proximity to structures and people as well as in an environment with rapidly changing winds, future passenger and cargo aircraft must be designed for both autonomous operations (i.e., without continuous human participation or supervision) and autonomous decision-making (i.e., able to determine what to do next in an unscripted situation without needing to consult a human).The same will be true for remotely operated aircraft with time delays between the operator and the aircraft (due to the distance between them) and periodic loss of communication (due to line of sight blockage by buildings).

   An air traffic management system with an open architecture and automated multilateral conflict detection and resolution is also critical to safe and efficient UAM operations. First, an open architecture, where adding, upgrading, and swapping components is easy, is essential to providing air traffic management in an ecosystem where vehicles and concepts of operations are rapidly changing. Second, automated multilateral conflict detection and resolution is essential given the proximity of flight vehicles to structures and people, and the rapidly changing winds in the urban environment. One needs only to consider four or more passenger VTOL aircraft operating below 400 feet within a one square-mile urban area to realize that conflict detection and resolution cannot be accomplished via traditional means, i.e., where a human observes the trajectories of flight vehicles via radar (or even ADS-B) to detect potential conflicts, determines suitable conflict resolution actions, and then verbally communicates these actions to vehicle operators. There simply is not enough time. Thus, conflict detection and resolution must be automated, and must be done on a multilateral basis, i.e., all potential conflicts between all flight vehicles must be detected and resolved simultaneously. This is particularly challenging since none of the automated conflict detection and resolution systems that have been fielded have been verified and validated for more than pair-wise (one-on-one) conflicts.

With regard to regulatory challenges: (1) there needs to be both greater clarity with respect to who owns (or at least has responsibility for) what portions of the airspace at low altitudes, and how the regulatory and operational responsibilities might be separated to facilitate the rapid yet safe development of air traffic management infrastructure and services; and (2) the FAA needs to develop a clear set of requirements for vehicle providers and operators, as well as for air traffic management infrastructure and service providers.

2. What roles will be played by the private and public (federal, state, local) sector to advance UAM transportation? How will the various participants in the UAM community collaborate on their roles to address issues as disparate as safety, environment, cybersecurity, zoning etc.?

Answer: Air traffic operations in each urban/metropolitan area will very likely be managed independently of operations in other urban/metropolitan areas. This is one of the considerations that has led me to the conclusion that some sort of public-private partnership will be formed between private and municipal entities, and that the FAA will play a regulatory role rather than providing air traffic management services.

Federal Government

The FAA plays a critical role with respect to setting requirements for vehicle providers and operators, as well as for air traffic management infrastructure and service providers. These requirements range in scope from certification to operational processes and procedures, and must also be consistent with a UAM architecture that allows private entities to participate in the development, deployment, and operation of the UAM infrastructure, and utilize the UAM infrastructure to provide services to other businesses or directly to consumers.

The work that NASA has been doing on UAS Traffic Management (UTM) is a strong foundation for the development of such an architecture. UTM has a modular framework where private enterprise can play an active role in all aspects of air traffic management. UTM needs to be accelerated so that a commonly accepted and workable architecture for UAM can be defined in short order, and so that the FAA can develop and promulgate requirements (and accompanying regulations) in a timely manner.

With regard to the environment, there is currently no significant effort on the part of the FAA or NASA to understand the potential impacts of UAM, or to develop solutions where necessary. The same is true with regard to privacy. There is some work which considers risk from the vehicle and system failure perspectives, but this work is independent of any work that is being done on cybersecurity, a topic where the DHS needs to play an active role. Thus, there needs to be a concerted and coordinated effort to:

1. Develop models for the source noise and failure characteristics of a wide range of proposed UAM aircraft in a representative range of operating conditions.

2. Develop noise and failure modeling frameworks that can be used within the context of a broader vehicle design tool to design low-noise, high-reliability vehicles, and to aid in certification.

3. Develop holistic analysis capability for UAM that enables estimation of appropriate measures of operational efficiency, noise impact, privacy, and risk.

4. Develop high-fidelity, computationally efficient algorithms and tools for the joint optimization of vertiport locations and flight trajectories.

<u>Local Government</u>
Zoning has been and will continue to be a local issue. That said, there is need for even greater coordination between air navigation service providers and local authorities, so that zoning rules are consistent with airspace structure and operations, and vice versa. For example, we do not want a situation where local government approves a building that protrudes into airspace designated for aircraft.

Local governments also have an important role to play in terms of determining the sensitivities of residents to UAM operations. In most visions for UAM, aircraft are either helicopters or propeller-based aircraft that use their propellers to achieve VTOL, and they take-off from and land at locations near residential areas. Locations near the homes of passengers and the recipients of packages will also be near the homes of other residents who might not be as receptive to noise emanating from rotating blades/propellers. Further, the proximity of the aircraft to windows and backyards is likely to raise issues with respect to privacy, and in virtually all locations there will be concerns with respect to safety.

Private Sector

As stated above, private enterprise should actively participate in the development, deployment, and operation of the UAM infrastructure and utilize the UAM infrastructure to provide services to other business or directly to consumers.

3. Safety concerns relative to VTOLs fall under two general buckets: safety of passengers on the vehicle and safety of the public outside the vehicle in the event of a catastrophe. How might issues of liability be handled when something goes wrong and people perish?

   Answer: Liability could be handled in a similar manner to automobiles, i.e., owners and operators of VTOLs would be required to have liability insurance before being allowed to operate, and minimum coverage values would be commensurate with the liabilities that could be incurred.

4. As our efforts to develop UAM progresses, where do we expect to see delays – in the development of technology, or in the ability of the public sector (federal, state, local governments) to keep up with innovation by implementing the relevant polices and regulations in a timely manner?

   Answer: I expect to see delays in the development and deployment of the UAM air traffic management infrastructure and services. I also expect to see delays with respect to the formulation of relevant policies and regulation at all levels of government. I believe that these delays can be reduced if all parties (government and industry) were to charter a team (with participation from the relevant government agencies and their divisions) to focus on introducing UAM in one or two metropolitan areas, thereby identifying and overcoming implementation challenges that are often not known a priori.

5. Besides NASA and FAA, what other federal agencies have a role to play in the design, development or rollout of VTOLs and the UAM system, and what are their roles?

   Answer: NASA and the FAA have had a long and distinguished history of developing both aircraft and air traffic management technologies, and of course the regulations and operational processes and procedures that have enabled the safe and orderly growth of aviation. Prior to the creation of the Department of Homeland Security (DHS), they also played a role in security alongside other federal agencies. However, since then the issue of transportation security has been the province of the DHS. There are clear security considerations with respect to UAM. Thus, I believe DHS needs to play a role, if nothing else than to specify security requirements. For example, it would be useful to know the minimum distance (with corresponding level of confidence and as a function of vehicle size) that vehicles must be kept away from both physical structures and people. Such requirements could then be converted into requirements for the capabilities of the UAM system (air traffic management services and vehicles).

6. With regard to developing VTOLs and the UAM system, is there any international coordination or collaboration, either with other governments or with companies registered in other nations? How do we walk the fine line between protecting sensitive information or trade secrets, yet still work with foreign counterparts to learn from and teach each other?

   Answer: Aviation is global enterprise. In fact, one might argue that the early adoption and continued use of global (operational and safety) standards have been critical enablers of aviation growth, as well as the ability of American companies to compete effectively in the global marketplace. The same will be true for UAM. While it is very likely, given the traditional role of the FAA and the very different nature of air traffic management for UAM, and desirable that air traffic management infrastructure and services in each urban area will be provided by different commercial entities to enable the positive effects of market-based competition, every vehicle that meets the regulatory requirements must be able to operate in every urban area in the world. Similarly, every provider of air traffic management infrastructure should be able to compete for business is every urban area. Thus, there is a need for collaboration with respect to communication and data standards, as well as performance requirements for both vehicles and air traffic management services.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"Urban Air Mobility – Are Flying Cars Ready for Take-Off?"

Dr. John-Paul Clarke, College of Engineering Dean's Professor, Georgia Institute of Technology; Co-Chair, 2014 National Research Council Committee on Autonomy Research for Civil Aviation

Questions submitted by Ranking Member Eddie Bernice Johnson, House Committee on Science, Space, and Technology

1. Your prepared statement paints a very sober look at the challenges we face in determining who will be at the controls of a UAM vehicle. A significant portion of commercial passenger flights are automated once the plane reaches cruising altitude.

    a. What additional capabilities and research are needed to enable take-off and landing activities?

    Answer: During cruise, the goal of both air traffic controllers and pilots is to get the aircraft under their control to a specified downstream location as efficiently as possible without conflicts with other aircraft. Take-off and landing are typically more challenging because aircraft must also be kept away from the ground (once the vehicle has taken off and of course prior to landing) and away from structures and people on the ground. While it is possible to automatically take-off and land commercial aircraft on a runway, these operations are not frequently conducted because they require both systems that are expensive to maintain to the required standards and specialized training for pilots. Furthermore, aircraft performing automatic landings fly longer final approach segments (the segment in line with the runway just before landing). This longer final approach segment also typically leads to a reduction in the overall landing rate. Automatic landings in an urban setting will require systems that provide guidance along curved paths. Such systems exist, however much work needs to be done to get them to the point where they can be utilized near buildings (especially tall buildings) that reflect GPS signals, which can introduce errors in estimates of position (i.e., multipath). Further, because rapid sensing, decision-making, and action are critical in flight vehicles that are operated close to structures and people, and in an environment with rapidly changing winds, onboard automation must have low-latency sensors and actuators, and greater autonomy.

b. How about the capabilities needed to safely and efficiently interface with unmanned aircraft systems and other traffic at low altitudes?

Answer: There needs to be an air traffic management system with an open architecture and automated multilateral conflict detection and resolution. Furthermore, this system must have a seamless interface with the air traffic management system that is used by manned commercial and general aviation aircraft so that there is complete situational awareness on the part of air traffic controllers, pilots, and unmanned flight vehicle operators (often referred to as remote pilots).

2. New York, Washington, D.C., and LA have all grappled with reducing or changing helicopter routes because of the noise generated from the aircraft. Your research focuses on aircraft trajectory prediction and optimization for more efficient air traffic operations and reducing environmental impact. How does trajectory research for UAM factor into safety, noise, privacy, and vertiport location?

   Answer: Trajectory prediction and optimization research are critical for UAM safety, noise, and privacy, as well as deciding where to locate vertiports. Safety, noise, and privacy are functions of the trajectory that is flown, which in turn is a function of vertiport location relative to the location of those who will be impacted by noise or loss of privacy. Thus, joint optimization of vertiport locations and flight trajectories can play an important role in reducing community objections to UAM operations based on safety, noise, and privacy concerns.

3. While the UAM industry envisions that vehicles will eventually be fully autonomous, we do not presently have the technology and safeguards to achieve that full autonomy in an operational setting. It has been four years since the National Academies report on autonomy research in civil aviation recommended urgent areas of research needed to achieve autonomous civil aviation, but you still view them as highly applicable.

   a. A significant portion of commercial passenger flights are automated once the plane reaches cruising altitude. What are the additional capabilities and research needed to enable take-off and landing activities?

   Answer: In addition to the capabilities and research described in my answer to question 1a, I also believe that the following four "most urgent and most difficult" research projects need to be addressed more rapidly than they are currently:

      1. Develop methodologies to characterize and bound the behavior of adaptive/nondeterministic systems over their complete life cycle.

2. Develop the system architectures and technologies that would enable increasingly sophisticated and increasingly autonomous systems and unmanned aircraft to operate for extended periods of time without real-time human cognizance and control.

3. Develop the theoretical basis and methodologies for using modeling and simulation to accelerate the development and maturation of advanced, increasingly autonomous systems and aircraft.

Develop standards and processes for the verification, validation, and certification of increasingly autonomous systems and determine their design implications.

b. How about the capabilities needed to safely and efficiently interface with unmanned aircraft systems and other traffic at low altitudes?

Answer: See answer provided to question 1b.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"Urban Air Mobility – Are Flying Cars Ready for Take-Off?"

Dr. John-Paul Clarke, College of Engineering Dean's Professor, Georgia Institute of Technology; Co-Chair, 2014 National Research Council Committee on Autonomy Research for Civil Aviation

Questions submitted by Representative Jacky Rosen, House Committee on Science, Space, and Technology

1. As the urban air mobility (UAM) industry continues to develop vehicles, it is imperative that we begin addressing safety and management issues. Congress, FAA, NASA, local jurisdictions, and industry will need to work together to answer a multitude of questions, including: who will police the skies or respond to potential accidents? Who will be liable? How will jurisdiction of physical airspace be divided?

    a. Can you address these questions and offer your thoughts as to how we tackle them?

       Answer: I believe that air traffic operations in each urban/metropolitan area will be managed by some sort of public-private partnership formed between private and municipal entities, and that the FAA will play a regulatory role, as opposed to simply providing air traffic management services. Jurisdiction of the physical airspace will be delegated to this entity by the FAA (or state and local governments where applicable).

       While the entity will have the job of managing the operations within the airspace that it controls, the FAA will set requirements for vehicle providers and operators, as well as for air traffic management infrastructure and service providers. These requirements will range in scope from certification to operational processes and procedures, and must be consistent with a UAM architecture that allows private entities to participate in the development, deployment, and operation of the UAM infrastructure, and utilize the UAM infrastructure to provide services to other business or directly to consumers.

       The entity will require an air traffic management system with an open architecture and automated multilateral conflict detection and resolution. NASA's UTM is a strong foundation for the development of such system, however UTM research and development needs to be accelerated so that a commonly accepted and workable architecture for UAM can be defined in short order, and so that the FAA can develop and promulgate requirements (and accompanying regulations) in a timely manner. Cybersecurity must also be address within the context of the air traffic management architecture, and DHS needs to play an active role.

Liability could be handled in a similar manner to automobiles, i.e., owners and operators of VTOLs would be required to have liability insurance before being allowed to operate, and minimum coverage values would be commensurate with the liabilities that could be incurred.

b. The FAA has "No Drone Zones" throughout the country and over some U.S. military facilities and airports – restricting unmanned aircraft flight. I represent a Congressional District that borders Las Vegas' McCarran International Airport, one of the busiest airports in the country. We are also less than twenty miles from Nellis Air Force Base and just over fifty miles from the Nevada Test and Training Range, which provides the largest air and ground military training space in the contiguous U.S., without interference from commercial aircraft. What will happen if UAM vehicles with passengers fly into this restricted airspace?

   Answer: "No Drone Zones" will be enforced either cooperatively or non-cooperatively. In both approaches the FAA, the U.S. military state and local governments, as well as private entities will define volumes of airspace from which drones are to be excluded (or alternatively in which drones are to be contained). With cooperative enforcement, automation onboard flight vehicles will determine when a drone is about to cross a prohibited boundary and take the necessary control actions to stay on its assigned side of the boundary. This approach is referred to as cooperative enforcement because it requires cooperation on the part of drone manufacturers (who must design and install the necessary software and hardware) and drone operators (who must ensure that the software and hardware are operational). With non-cooperative enforcement, a ground-based system will determine when a drone is about to cross a prohibited boundary and disable the drone by mechanical or electromagnetic means. This approach requires no cooperation on the part of drone manufacturers or operators.

Responses by Dr. Eric Allison

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"Urban Air Mobility – Are Flying Cars Ready for Take-Off?"

Dr. Eric Allison, Head of Aviation Programs, Uber

Questions submitted by Chairman Lamar Smith, House Committee on Science, Space, and Technology

1. There are a series of challenges that need to be overcome before UAM can come to fruition. In your opinion, what are the top two most significant technology and regulatory challenges that need to be overcome to make UAM a reality?

   Answer: The two most significant technical challenges are:

   - Manufacturing certified aircraft at large scale. Global aircraft production volumes today are in the low thousands. In order to realize our vision of UAM at scale, we will need to produce eVTOL aircraft at significantly higher rates. This is primarily a challenge of producing high-performance composite aerostructures faster and more affordably than is presently possible, but we believe we there is a path forward by applying modern manufacturing techniques such as those used in the luxury car industry.
   - Lightweight Batteries. To achieve Uber's mass-market price targets, the vehicles operating on the Uber Elevate network will likely be all-electric. The energy density of today's battery packs is not adequate for long-range missions, nor are packs safe enough for aerial ridesharing. This is why Uber has hired experienced technical leadership in this area to work with leading energy storage companies to advance the state-of-the-art for batteries in our aircraft.

   As technology develops and the industry evolves, there will be many regulatory issues to address. If we were to pick two that were the most pressing at this point it would be the following:

   - A patchwork of local rules governs the design, construction, and operation of heliports/skyports. The scaled deployment of this technology depends on greater uniformity, especially since the federal government has already recognized the imperative of national uniformity in this general subject matter area (aviation). Uber can contribute toward this goal through collaboration with industry committees like ASTM International to develop standards that allow for scalable operations.
   - Scaled operations would also benefit from a clear commitment by the federal government to certify eVTOL aircraft under the recently updated Part 23

(Amendment 64). We believe the adjacent operational and piloting rules have sufficient flexibility to support the innovation involved in eVTOL operations, while maintaining the highest standards of aviation safety. However, this approach will require support from the regulators positioned to interpret these rules and a willingness to proffer interpretations that convey a sufficient level of certainty to the investing community.

2. What roles will be played by the private and public (federal, state, local) sector to advance UAM transportation? How will the various participants in the UAM community collaborate on their roles to address issues as disparate as safety, environment, cybersecurity, zoning etc.?

   Answer: UAM transportation would undoubtedly benefit from close collaboration between the public and private sectors. Within that collaboration, each set of actors can facilitate and serve important individual roles.

   Private companies will be responsible for designing and building the aircraft and some of the infrastructure, crafting a use case for productive use of these new systems and vehicles, operating the aircraft, and interfacing with consumers.

   Federal entities will define means of compliance for certifying the aircraft, and will define, with input from the private sector, the procedures for integrating UAM air traffic into the national airspace.

   Local entities will define certain environmental, fire safety, and zoning requirements for infrastructure. Local entities may also invest in infrastructure as part of their transportation programs.

   Uber is partnering with global leaders in aircraft manufacturing such as Bell, Aurora, Embraer, Pipistral, and Kareem Aircraft to design new aircraft that will lead the revolution in urban aviation. We are also working with other companies such as ChargePoint and Hillwood to develop critical infrastructure such as quick vehicle rechargers and vehicle integration with buildings.

3. Safety concerns relative to VTOLs fall under two general buckets: safety of passengers on the vehicle and safety of the public outside the vehicle in the event of a catastrophe. How might issues of liability be handled when something goes wrong and people perish?

   Answer: Safety is the highest priority at Uber. The successful deployment of VTOLs and establishing consumer confidence fundamentally rests on safe operations.

Safety is built into our systems from the first steps of the design phase. For instance, Uber is developing systems that have multiple levels of redundancy so there are not one single point of failure. The use of multiple electric motors, controls, and electrical architecture reduces the chance of a catastrophic failure.

Additionally, the aviation industry has developed systems, through insurance and otherwise, to address liability issues in the event of an incident. We envision that these systems will offer lessons and valuable guidance for VTOL operations.

4. As our efforts to develop UAM progresses, where do we expect to see delays – in the development of technology, or in the ability of the public sector (federal, state, local governments) to keep up with innovation by implementing the relevant polices and regulations in a timely manner?

   Answer: Challenges are an inherent part to any effort seeking to improve our transportation infrastructure, especially in this ambitious effort to create a new transportation platform. Uber has issued a detailed White Paper, which has been inserted into the hearing record, detailing some of those challenges, and how Uber intends to address those challenges.

   The certification process for new aircraft presents a resource intensive effort -- both for the private sector and for regulators. We appreciate the safety benefits that flow from this type of fulsome review. We are hopeful that, with the benefit of revised Part 23, the FAA will work with industry partners to identify reasonable means of establishing (in a reasonable timeframe) the means of compliance with these revised standards, especially as applied to VTOLs.

5. Besides NASA and FAA, what other federal agencies have a role to play in the design, development or rollout of VTOLs and the UAM system, and what are their roles?

   Answer: Uber's White Paper details a series of steps that likely will require close coordination between industry and the federal government. This collaboration touches not only on aircraft design and operation (areas where we look forward to partnering with the FAA, the broader Department of Transportation, and NASA), but also issues ranging from security to spectrum use, which fall within the jurisdiction of a number of federal agencies.

6. With regard to developing VTOLs and the UAM system, is there any international coordination or collaboration, either with other governments or with companies registered in other nations? How do we walk the fine line between protecting sensitive information or trade secrets, yet still work with foreign counterparts to learn from and teach each other?

   Answer: Uber believes that international coordination and collaboration will be a key to bringing our product to market. Given that, Uber has announced an intent to partner with three 'launch cities'. This will allow for a balance between focus and city diversity that will set the service up for long-term success.

   Dallas and Los Angeles have been announced as the first two launch cities, and we are now seeking an international city as the third partner. These three cities will be the first to offer uberAIR flights, with the goals of operating demonstrator flights starting in 2020 and beginning commercial operations in 2023.

   We've been thrilled by the inbound interest from the international community, and are working towards an announcement regarding the third launch city. Uber is a company that operates in more than 600 cities in 65 countries, and would like to bring this product to as many people as possible. To achieve this we must work with civil aviation agencies from around the world such as the European Aviation Safety Agency (EASA).

   Uber is also collaborating with manufacturing partners that are both foreign and domestic, allowing us to tap into a greater reserve of knowledge and technology. Uber is taking an ecosystem approach which will require contributions from many partners to bring their expertise to solving the many challenges of making urban air mobility a reality.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"Urban Air Mobility – Are Flying Cars Ready for Take-Off?"

Dr. Eric Allison, Head of Aviation Programs, Uber

Questions submitted by Ranking Member Eddie Bernice Johnson, House Committee on Science, Space, and Technology

1. According to a 2015 GAO report, newly developed aircraft may be particularly vulnerable to hacking due to their onboard computer systems. If a hacker is able to overcome the aircraft's firewall, they could then commandeer the aircraft, install a virus into flight control computers, and take over the warning systems or navigation systems, among other potentially catastrophic actions. What measures are Uber and its manufacturing partners taking to ensure that UAM vehicles are secure against cyber threats? What agencies are you working with?

   Answer: We agree that the success of UAM will require absolute attention to safety and cybersecurity. In this respect, Uber Elevate faces cyber security demands that are not that different from those facing conventional aviation operators. We firmly believe that incorporating cybersecurity is critical to the design of the VTOL aircraft and our air traffic management and communications, to commit to remaining mindful of the imperative to utilize well-established techniques for mitigating cybersecurity risks.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"Urban Air Mobility – Are Flying Cars Ready for Take-Off?"

Dr. Eric Allison, Head of Aviation Programs, Uber

Questions submitted by Representative Daniel Lipinski, House Committee on Science, Space, and Technology

1. Given that Uber's vision is to operate thousands of aircraft in a single metropolitan area, can you please explain how this could be done in a region as complex as Chicago? As you know, in that region, which includes my district, you have major airports, Midway and O'Hare, and a number of smaller airports, such as Lewis Airport in my district. How will you keep your fleet away from larger aircraft, both General Aviation and commercial, and from smaller unmanned aerial systems in a complex airspace such as the Chicago region?

   Answer: Successful deployment of VTOLs in and around an urban area undoubtedly requires clear expectations to avoid conflicts between large commercial aircraft and new VTOL operations. Some of this can be achieved, with small volumes of aircraft, using existing helicopter flight paths that already are designed as separate from commercial traffic. Flight that operates between 500 and 1500 feet AGL will further avoid this type of conflict by remaining clear of those altitudes most typically utilized by commercial and small UAS traffic (>10,000 feet and <400 feet, respectively). Recognizing the importance of this integration effort, we are under a Space Act Agreement with NASA to test through simulation the integration of Uber Air-style traffic with the commercial traffic flows at DFW. These simulations will allow us to design systems that appropriately integrate with existing traffic.

2. NASA has been heavily engaged in research and development efforts to advance innovations in propulsion, simplified vehicle operations and automation. Dr. Shin highlighted some of NASA's efforts in his testimony. The FAA also plays a critical role with regard to certification, operations and access to the airspace.
   a. What opportunities and challenges do you see around access to infrastructure, namely vertical takeoff and landing sites, and how should this infrastructure relate to existing public works projects and funding?

      Answer: We see public skyports as a great way for cities and private entities to invest in transportation with low infrastructure requirements. The node-based system (as opposed to roads and rails which are path based) will enable access to the urban center for remote communities with significantly reduced infrastructure cost.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"Urban Air Mobility – Are Flying Cars Ready for Take-Off?"

Dr. Eric Allison, Head of Aviation Programs, Uber

Questions submitted by Representative Jacky Rosen, House Committee on Science, Space, and Technology

1. As the urban air mobility (UAM) industry continues to develop vehicles, it is imperative that we begin addressing safety and management issues. Congress, FAA, NASA, local jurisdictions, and industry will need to work together to answer a multitude of questions, including: who will police the skies or respond to potential accidents? Who will be liable? How will jurisdiction of physical airspace be divided?

   a. Can you address these questions and offer your thoughts as to how we tackle them?

      Answer: Aviation has built an admirable record of public safety, in part due to the strong public/private partnerships that focus on preserving and enhancing safety. Uber's plans contemplate building on that proven record of success. In our view, VTOL operations would not demand a wholesale reordering of government functions with regard to aviation regulation. The FAA and the U.S. Department of Transportation are well positioned to continue exercising regulatory jurisdiction over the nation's airspace, adapting as needed to technological innovations. Further, we envision other local, state, and federal partners continuing to play crucial roles in preserving safety on issues ranging from security to safety and infrastructure support.

   b. The FAA has "No Drone Zones" throughout the country and over some U.S. military facilities and airports – restricting unmanned aircraft flight. I represent a Congressional District that borders Las Vegas' McCarran International Airport, one of the busiest airports in the country. We are also less than twenty miles from Nellis Air Force Base and just over fifty miles from the Nevada Test and Training Range, which provides the largest air and ground military training space in the contiguous U.S., without interference from commercial aircraft. What will happen if UAM vehicles with passengers fly into this restricted airspace?

      Answer: As the technology develops, aircraft can be "geofenced" -- meaning pre-programmed to avoid prohibited airspace. Geofencing will mitigate intrusions into no fly zones. Piloted systems can operate much as they do today -- with clear pilot instructions to avoid prohibited airspace.

Responses by Mr. Michael Thacker

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"Urban Air Mobility – Are Flying Cars Ready for Take-Off?"

Mr. Michael Thacker, Executive Vice President, Technology & Innovation, Bell

Questions submitted by Chairman Lamar Smith, House Committee on Science, Space, and Technology

1. There are a series of challenges that need to be overcome before UAM can come to fruition. In your opinion, what are the top two most significant technology and regulatory challenges that need to be overcome to make UAM a reality?

   Answer: The base technologies required to implement UAM in a manner that can grow into an entirely new branch of aviation transport are available today. The technology challenges revolve around the maturation needed for practical application.

   One of the most exciting elements of most of the new UAM concepts is the use of distributed hybrid or electric propulsion for both primary power and primary control. The critical technology elements needed exist, but some lack in practical maturity. Batteries, for instance, need improved weight and volume energy density to make more commercially viable missions possible. Batteries also need improved thermal management and reduced cost.

   For autonomous operations, a key requirement is positive aircraft separation. Numerous approaches are being developed and some elements of the solution, like ASD-B, are mature or maturing rapidly. Weight, cost and distribution of equipment between aircraft and ground are areas needing further development.

   From a regulatory perspective, the FAA has implemented the Small Airplane Revitalization Act of 2013 (SARA) which created a very powerful tool for the safe and efficient introduction of new technologies. If the FAA prioritizes the use of this new tool for VTOL aircraft, the certification and global recognition of these products can be expedited and standardized. The aviation community has already begun the development of new standards which address many of the needs of the VTOL community.

   With a reasonable framework for vehicle certification within reach, the largest regulatory challenges are expected to be operational. An integrated approach to vehicle, operational and airspace requirements is needed to enable successful deployment of UAM.

2. What roles will be played by the private and public (federal, state, local) sector to advance UAM transportation? How will the various participants in the UAM community collaborate on their roles to address issues as disparate as safety, environment, cybersecurity, zoning etc.?

   Answer: As UAM will be a significant and long-term facet of aviation in the near future, an integrated approach is critical. Traditionally, all aspects of aviation have been under federal jurisdiction (with FAA understanding and mediating specific needs at state and local levels) except for certain aspects of airport facilities. It will be of critical importance to assure that the same approach is maintained with UAM. Obviously, the issues of noise and safety are important to many stakeholders, but assuring the FAA maintains purview of airworthiness, operations, air traffic and aviation noise/emissions is necessary to allow for a consistent and positive outcome for all parties. The UAM community is also working collaboratively to develop common approaches to these key challenges.

3. Safety concerns relative to VTOLs fall under two general buckets: safety of passengers on the vehicle and safety of the public outside the vehicle in the event of a catastrophe. How might issues of liability be handled when something goes wrong and people perish?

   Answer: The VTOL community is working to implement the safest possible mobility solutions. Of key importance to the safety and success of UAM is successful safety partnership between industry and regulators and the ability to share data and operational experience and implement changes and solutions as necessary.

   When unfortunate accidents do happen, the current aviation system provides a good starting point for the UAM model. The existing response mechanisms and consequences can be adapted for application to UAM operations. Likewise, from a liability perspective, existing models can be adapted to provide a basis for ensuring adequate recourse for involved parties.

4. As our efforts to develop UAM progresses, where do we expect to see delays – in the development of technology, or in the ability of the public sector (federal, state, local governments) to keep up with innovation by implementing the relevant polices and regulations in a timely manner?

   Answer: If properly motivated, resourced and prioritized, the FAA will be able to verify the safe design of VTOL aircraft, but there is also a need to focus on the efficient operations of these aircraft. It is important that the FAA retain authority over aviation and a centralized, agency-controlled aviation system is maintained for UAM.

   One of the greatest areas of opportunity is for realistic operational testing. Initiatives like the FAA UASIPP and the NASA SIO will help address this need. FAA support for advanced testing of large UAM and/or complex operations in realistic, even urban, environments is needed to be able to demonstrate capability and progress toward regular commercial operations that meet the high safety standards of our aviation system.

5. Besides NASA and FAA, what other federal agencies have a role to play in the design, development or rollout of VTOLs and the UAM system, and what are their roles?

   Answer: Department of Energy (DOE) – The DOE can support fundamental research in energy storage and management technologies.

   National Transportation Safety Board (NTSB) – As in the existing aviation system, the NTSB will play a critical role in accident reporting and investigation.

   Federal Communications Commission (FCC) – Air to ground and air to air communications are critical links in the operational, control and safety systems of the UAM vehicles and operational models.

   Numerous Federal agencies have active cyber-security programs. Information and best practice sharing for protecting critical hardware, software and communications will help enable safe and reliable UAM operations.

6. With regard to developing VTOLs and the UAM system, is there any international coordination or collaboration, either with other governments or with companies registered in other nations? How do we walk the fine line between protecting sensitive information or trade secrets, yet still work with foreign counterparts to learn from and teach each other?

   Answer: Coordination is necessary with other international regulatory agencies including EASA, TCCA, JACB, CAAC to ensure that the aircraft can be operated globally. Without harmonized global requirements, vehicles could require location-specific features that could significantly limit market access and/or result in higher vehicle costs.

   It should also be noted that substantial investments in this area are being made outside the U.S., and the ability of domestic industry to compete globally is dependent on the speed and effectiveness of the actions taken to support and enable UAM development and operations.

   When working with foreign regulators or business entities, the sensitive or proprietary information may include aircraft design, command and control systems, detect and avoid systems, and cyber-security. In each of these cases, Minimum Operational Performance Standards (MOPS) should be shared and met, but only limited details of achieving the

MOPS consistent with compliance to U.S. government requirements and with business intellectual property protocols should be shared.

Since aviation is already a global industry, most businesses already have processes in place to protect sensitive information for both competitive and compliance reasons. Information protection is governed by several requirements including but not limited to the U.S. Department of Commerce Bureau of Industry and Security (BIS) and U.S. Department of State Directorate of Defense Trade Controls (DDTC). Beyond governmental compliance, most businesses use internal policies and procedures to protect intellectual property and trade secrets.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"Urban Air Mobility – Are Flying Cars Ready for Take-Off?"

Mr. Michael Thacker, Executive Vice President, Technology & Innovation, Bell

Questions submitted by Representative Daniel Lipinski, House Committee on Science, Space, and Technology

1. NASA has been heavily engaged in research and development efforts to advance innovations in propulsion, simplified vehicle operations and automation. Dr. Shin highlighted some of NASA's efforts in his testimony. The FAA also plays a critical role with regard to certification, operations and access to the airspace.

    a. How can the newly rewritten FAA Part 23 regulations for general aviation aircraft be used to safely bring these aircraft to market, and what else does the FAA need to do to support this process?

    Answer: The new FAA part 23 rules are well suited to address the design certification of new UAM products. Because these rules are based on safety objectives instead of specific technologies (as the other regulatory parts are) they work well for many UAM aircraft. Special conditions will be needed to address the vertical and transition flight elements of these vehicles, and these should also be based on safety objectives rather than prescriptive solutions. To position U.S. aviation for the future, including but not limited to UAM, the risk-based continuum of safety philosophy of the Part 23 re-write should be more broadly applied to vehicle operations (Parts 61, 91 and 135) and airspace as well as other aircraft regulations like Parts 25, 27 and 29.

    A certification basis is an agreed set of airworthiness requirements for a product to obtain a Type Certificate. Equally important and often times more difficult to establish are the means of compliance. The means of compliance are a detailed standards and methodologies that, if met, accomplish the safety intent of the regulations. The UAM community is already working to develop standards, through groups such as ASTM, which can serve as possible detailed means of compliance for the revised Part 23 rules.

    As mentioned during the oral testimony, one of the most critical needs from the FAA is an integrated and consistent regulatory framework across all of the safety system elements (vehicle, operations and airspace) where safety mitigations can be addressed in different ways for different products and operating models across the three contributing elements to achieve the high safety expectations of our great aviation system.

To develop the systems needed to achieve expected safety outcomes with more autonomous aircraft, development work will need to be completed by both industry and regulators. The FAA and NASA have an UAS Traffic Management (UTM) Research Transition Team (RTT) Plan for cooperative work in this area through September of 2020. We support these efforts, but also need the FAA to provide broader delegation of authority for unmanned airworthiness findings by established applicants and more rapid approval of Certificates of Authorization (COA) and Special Airworthiness Certificates in the experimental category for unmanned aircraft systems (UAS) and optionally piloted aircraft (OPA). These provisions should address specific exemptions to test advanced capabilities like beyond visual line of sight (BVLOS) and operations over populated areas, assuming the applicants have sufficient safety mitigations and pedigree.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"Urban Air Mobility – Are Flying Cars Ready for Take-Off?"

Mr. Michael Thacker, Executive Vice President, Technology & Innovation, Bell

Questions submitted by Representative Jacky Rosen, House Committee on Science, Space, and Technology

1. As the urban air mobility (UAM) industry continues to develop vehicles, it is imperative that we begin addressing safety and management issues. Congress, FAA, NASA, local jurisdictions, and industry will need to work together to answer a multitude of questions, including: who will police the skies or respond to potential accidents? Who will be liable? How will jurisdiction of physical airspace be divided?

    a. Can you address these questions and offer your thoughts as to how we tackle them?

       Answer: The existing aviation model is a good starting point to address the questions raised. The safety and success of UAM is contingent upon a federalized approach to oversight and management under the FAA, as traditionally is the case. The specific issues at hand fit well within the purview of the FAA and maintaining this path forward is the only viable path for successful integration of UAM.

    b. The FAA has "No Drone Zones" throughout the country and over some U.S. military facilities and airports – restricting unmanned aircraft flight. I represent a Congressional District that borders Las Vegas' McCarran International Airport, one of the busiest airports in the country. We are also less than twenty miles from Nellis Air Force Base and just over fifty miles from the Nevada Test and Training Range, which provides the largest air and ground military training space in the contiguous U.S., without interference from commercial aircraft. What will happen if UAM vehicles with passengers fly into this restricted airspace?

       Answer: As with the prior question, the existing aviation model provides a good starting point. Inadvertent or intentional penetration of restricted airspace can and does happen today. The existing response mechanisms and consequences can be adapted for application to UAM operations.

Responses by Ms. Anna Mracek Dietrich

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"Urban Air Mobility – Are Flying Cars Ready for Take-Off?"

Ms. Anna Mracek Dietrich, Co-Founder, Terrafugia Inc.

Questions submitted by Chairman Lamar Smith, House Committee on Science, Space, and Technology

1. There are a series of challenges that need to be overcome before UAM can come to fruition. In your opinion, what are the top two most significant technology and regulatory challenges that need to be overcome to make UAM a reality?

   Answer: In my opinion, the aircraft technology and the mechanisms used to certify it are reasonably mature at this time. This leaves the other two "legs of the stool": operations and airspace access/air traffic control. Operations include infrastructure access, and the ability to appropriately accommodate in both the regulatory and training/licensing spaces the advantages of simplified vehicle operations (where the aircraft systems supplement the capability of a human pilot) and autonomy (where the aircraft systems would replace certain areas of the human pilot's role). Airspace access/air traffic control challenges arise as our current air traffic control constructs are not sufficient for the number of UAM flights that are anticipated. Distributed control and aircraft self deconfliction will need to augment or even replace traditional human serial voice communication. Segregation, which has been proposed as a possible solution, will work only in the short term and is not capable of providing either the capacity or safety that is needed in the long run.

2. What roles will be played by the private and public (federal, state, local) sector to advance UAM transportation? How will the various participants in the UAM community collaborate on their roles to address issues as disparate as safety, environment, cybersecurity, zoning etc.?

   Answer: There is already significant industry and regulator collaboration happening through both standards bodies like ASTM International under which committees are drafting and maintaining technical standards that provide the means of compliance to the 14 CFR Part 23 rules. These standards can (and in many cases already do) cover the subject areas that you mention. Industry groups, like the General Aviation Manufacturers Association (GAMA) are also effectively tackling issues related to the UAM and eVTOL industry by providing a forum for industry collaboration and a channel for regulator communication. Private players like Uber are also serving an important role in their efforts to connect relevant stakeholders, for instance with their Elevate conference (held so far in 2017 in Dallas and 2018 in Los Angeles). Terrafugia is investing significant manpower in these efforts as well through participation and leadership roles in ASTM, GAMA, and other industry efforts. This existing communication and collaboration between industry, regulators, and local state and federal government should be supported and continued. Forums like the hearing on the 24th of July 2018 are a key part of opening and maintaining the necessary communication channels and are greatly appreciated.

3. Safety concerns relative to VTOLs fall under two general buckets: safety of passengers on the vehicle and safety of the public outside the vehicle in the event of a catastrophe. How might issues of liability be handled when something goes wrong and people perish?

   <u>Answer</u>: As an engineer and entrepreneur, my priority is of course minimizing the possibility of such a catastrophe, but you are correct that even the safest systems can encounter failures that lead to injury or loss of life, and it is prudent to consider such a possibility, however remote.

   I am not a lawyer, so my ability to comment here is limited. There is significant legal precedent around aircraft accidents and incidents. Today, the pilot in command is responsible for the safe operation of the aircraft. If autonomy capabilities mature to the point where there is no longer a dedicated human pilot responsible for the safe operation of a flight, it is anticipated that manufacturers may assume greater liability. New constructs in liability and insurance may be needed to address this shift, which could involve Congressional action. I do not know exactly what those constructs may be. Other industries may provide useful constructs to consider, for example, the alternative liability system for vaccine injuries, or new constructs may need to be developed.

4. As our efforts to develop UAM progresses, where do we expect to see delays – in the development of technology, or in the ability of the public sector (federal, state, local governments) to keep up with innovation by implementing the relevant polices and regulations in a timely manner?

   <u>Answer</u>: It is of course difficult to predict exactly how a new industry will develop, and there will likely be delays on all of the fronts that you mention. The industry's ability to minimize those delays will depend largely on the willingness of both the public sector and regulators to continue to collaborate with manufacturers and operators to find a safe and efficient solution to whatever challenges arise. Continuing to advance the policy and regulatory environment in step with the technology development will result in the safest and quickest deployment of UAM aircraft. From the perspective of a manufacturer, however, the largest schedule uncertainty comes from policy and regulatory considerations as technological development challenges are more directly under our research, development, engineering, and manufacturing control.

5. Besides NASA and FAA, what other federal agencies have a role to play in the design, development or rollout of VTOLs and the UAM system, and what are their roles?

   Answer: While ultimately the impact of the UAM industry will likely be farther reaching that even I am imagining at this point, I would start by adding the EPA, the DOT, and the FCC to this list. The EPA for emissions requirements – particularly for power generation as even electric propulsion can have a negative environmental impact and contribute to climate change if the electricity is not generated in a clean and renewable fashion. The DOT should be involved for infrastructure construction. As discussed below, vertiports should be considered as public transportation infrastructure just as highways and rail are today. The FCC will have a role to play as one of the keys to success for UAM is vehicle-to-vehicle and vehicle-to-ground communication. The industry is already working with 5G cell service providers on a potential solution in this area, but it will be important that the FCC protects aviation frequencies and vehicle-to-vehicle digital safety communications in the 5.9 GHz range and to more generally support this effort. Terrafugia also works with NHTSA, as our vehicles drive and are subject to the Federal Motor Vehicle Safety Standards (FMVSS), but this is not universal to the UAM industry.

6. With regard to developing VTOLs and the UAM system, is there any international coordination or collaboration, either with other governments or with companies registered in other nations? How do we walk the fine line between protecting sensitive information or trade secrets, yet still work with foreign counterparts to learn from and teach each other?

   Answer: There is strong collaboration between international civil aviation authorities (e.g., EASA) both within the ASTM industry consensus committees and independently. This is important for the industry as it will ensure a harmonized set of aircraft certification requirements across international markets. It is also important and beneficial that we have participation from manufacturers across the world contributing their expertise and experience to developing these standards as it raises the level of safety for all. It is also my opinion that as the problems we face get ever more challenging, there is increasing need for and benefit of global collaboration.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"Urban Air Mobility – Are Flying Cars Ready for Take-Off?"

Ms. Anna Mracek Dietrich, Co-Founder, Terrafugia Inc.

Questions submitted by Ranking Member Eddie Bernice Johnson, House Committee on Science, Space, and Technology

1. In your prepared statement, you indicate that Terrafugia is "*now a sister company of Volvo Car Group and other international automotive brands under Zhejiang Geely Holding Group*", you further state that the 2017 acquisition received approval from all relevant regulators, including the Committee on Foreign Investment in the United States (CFIUS). In addition, one of the slides you presented during your testimony characterized Terrafugia as a U.S. company.

   a. Can you clarify how the purchase of Terrafugia in 2017 by a Chinese company enables Terrafugia to be characterized as a U.S. company?

      Answer: Terrafugia is incorporated as a C Corporation under Delaware law. Terrafugia pays taxes in the United States. The majority of Terrafugia's employees, including senior leadership, live, work, and pay taxes in the U.S. In addition, Terrafugia's operating headquarters is in Woburn, MA, with additional facilities in New Hampshire and California.

   b. Were there specific conditions placed on Geely and Terrafugia as part of the CFIUS approval? What are these conditions? Do any pertain to the sharing of information Terrafugia develops independently or acquires from other U.S. entities, both commercial and governmental? If so, can you characterize how such information must be safeguarded?

      Answer: No specific conditions to Terrafugia were imposed.

   c. Was Terrafugia required to enter into any mitigation agreements to address security risks as part of the CFIUS review?

      Answer: No mitigation agreements were required.

   d. Is Terrafugia eligible for entering into partnerships with U.S. federal entities such as NASA? Are any such partnerships in effect and if so, with whom? Are any conditions placed on the intellectual property produced?

Answer: As Terrafugia is majority owned by a foreign entity, it would be required to establish internal firewalls and protocols to prevent the export of controlled technologies if we wished to access certain NASA technologies. It is our intention to establish the necessary internal protections (as is common in the aerospace industry) so that Terrafugia could potentially access such technology in the future. Even without a NASA partnership, as a US-based developer of advanced technologies, we must be careful regarding the export of controlled technologies. Although Terrafugia is owned by a foreign entity, there are technologies that cannot be transferred to our ownership if we possessed them (without an exemption). Since all technologies that Terrafugia is developing are for commercial purposes only, we may apply for such exemptions in the future if we wish to transfer such technologies to foreign markets. This practice is common in the aviation industry surrounding the export of advanced aircraft and engines for commercial use.

e. Can Terrafugia partner with commercial U.S. entities, such as Uber? Are there any such partnerships? If so, with whom?

   Answer: Yes, such partnerships are possible, but none are in place at this time.

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Questions submitted by Representative Daniel Lipinski, House Committee on Science, Space, and Technology

1. NASA has been heavily engaged in research and development efforts to advance innovations in propulsion, simplified vehicle operations and automation. Dr. Shin highlighted some of NASA's efforts in his testimony. The FAA also plays a critical role with regard to certification, operations and access to the airspace.

    a. How can the newly rewritten FAA Part 23 regulations for general aviation aircraft be used to safely bring these aircraft to market, and what else does the FAA need to do to support this process?

    Answer: The newly rewritten 14 CFR Part 23 Amendment 64 is a key part of safely bringing new and innovative aircraft to market. By focusing on the safety intent behind each of the previous prescriptive requirements in Amendment 62 and capturing that in the new rules, the FAA freed manufacturers to innovate in ways that were previously impractical. With this innovation comes the potential for an even higher level of safety as new technologies can now be incorporated into aircraft that would have been too cumbersome to certify under the old Part 23.

    In conjunction with rewriting Part 23, an international industry consensus standards body, including academia, NASA, manufacturers, users, and regulators from around the world, is working under ASTM to create, maintain, and expand a library of technical standards that provide a means of compliance for the safety-intent-based Part 23 Amdt 64 rules. These standards can be created and revised on a much shorter time frame than a Rulemaking typically requires, making them agile enough to keep up with the emerging UAM-enabling technology. This combination of industry consensus standards and a safety-intent-based rule will allow UAM aircraft to be brought to market more safely and much more expeditiously than would have previously been possible.

    In addition to aircraft certification, there are two other components that need to come together for the UAM fleet to take off. These are: operational considerations and airspace access/air traffic control. Operational considerations include how simplified vehicle operations (where the aircraft systems supplement the capability of a human pilot) and autonomy (where the aircraft systems would replace certain areas of the human pilot's role) are accounted for in training and flight operations. Airspace access and air traffic control issues include creating a robust distributed communication and deconfliction network between all aircraft in the NAS and moving away from serialized voice communication as the sheer number of UAM aircraft, particularly when combined with UAS and existing traffic, will exceed the capacity of traditional ATC protocols. Industry is eager to collaborate with the appropriate branches of the FAA to realize safe and effective solutions in both of these areas, much as industry has stepped up to support the aircraft certification efforts through the rulemaking and standards creation process, but traction in these areas has been hard to establish.

b. What opportunities and challenges do you see around access to infrastructure, namely vertical takeoff and landing sites, and how should this infrastructure relate to existing public works projects and funding?

Answer: I firmly believe that vertical takeoff and landing sites (vertiports) should be considered critical public transportation infrastructure. Just as existing airports and highways are built and maintained with public money, so too should vertiports. While there will always be private roads (just as there are private airports – most of which are grass strips for hobbyist use), and likewise private vertiports, I believe that a lack of public vertiports will result in a less equitable distribution of the benefit of this technology as well as in the creation of monopolistic situations. If appropriately located and funded, vertiports and UAM access have the potential to address transit deserts in underserved neighborhoods and to connect rural areas to the healthcare, jobs, and other benefits of nearby urban centers.

Additionally, while the unique circumstances of each community should be given consideration (as the landing pattern for local GA airports can be prescribed to keep aircraft over less populated land on one side of the field), it is important that the FAA maintain its federal preemption over vertiport locations and operations. To date, the FAA has done a very good job of creating a safe and effective air transportation system in the U.S., which has been emulated globally. It would both be a detriment to safety and a barrier to market entry if each local municipality was allowed to draft unique vertiport regulations. This patchwork approach would be extremely difficult to navigate and would result in delayed implementation and potentially unsafe conditions.

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Questions submitted by Representative Jacky Rosen, House Committee on Science, Space, and Technology

1. As the urban air mobility (UAM) industry continues to develop vehicles, it is imperative that we begin addressing safety and management issues. Congress, FAA, NASA, local jurisdictions, and industry will need to work together to answer a multitude of questions, including: who will police the skies or respond to potential accidents? Who will be liable? How will jurisdiction of physical airspace be divided?

    a. Can you address these questions and offer your thoughts as to how we tackle them?

       Answer: It is important to keep in mind that there are already highly functional systems in place today to manage personal and commercial air traffic, which can respond to safety issues and any incidents or accidents that may occur. The National Transportation Safety Board (NTSB), FAA, and local first responders are already doing this work and doing it well. Although the forecasted increase in operations associated with UAM flights will necessitate evolution or expansion in these areas, we already have a solid foundation on which to build.

       As for the question of liability, I am not a lawyer, so my ability to comment is limited. There is significant legal precedent around aircraft accidents and incidents. Today, the pilot in command is responsible for the safe operation of the aircraft. If autonomy capabilities mature to the point where there is no longer a dedicated human pilot responsible for the safe operation of a flight, it is anticipated that manufacturers may assume greater liability. New constructs in liability and insurance may be needed to address this shift, which could involve Congressional action. I do not know exactly what those constructs may be. Other industries may provide useful constructs to consider, for example, the alternative liability system for vaccine injuries, or new constructs may need to be developed.

       As for physical airspace, it is my opinion that the less "divided" it is, the safer and more efficient the skies will be. As aircraft gain the ability to communicate directly with each other, distributing control organically and reducing, and eventually potentially eliminating, the need for centralized voice-based air traffic control, the tools and delineations that were necessary to keep track of the airspace before human controllers had computational assistance will not be as critical. This distributed control model – in which aircraft of all types and sizes are able to directly deconflict with each other – has the potential to be significantly safer and more efficient operationally with many more aircraft than the current construct. For areas where a physical division is still advantageous (e.g., the military test ranges as you describe below), geo-fencing can be employed to reduce or even eliminate the likelihood of intrusion.

b. The FAA has "No Drone Zones" throughout the country and over some U.S. military facilities and airports – restricting unmanned aircraft flight. I represent a Congressional District that borders Las Vegas' McCarran International Airport, one of the busiest airports in the country. We are also less than twenty miles from Nellis Air Force Base and just over fifty miles from the Nevada Test and Training Range, which provides the largest air and ground military training space in the contiguous U.S., without interference from commercial aircraft. What will happen if UAM vehicles with passengers fly into this restricted airspace?

Answer: Currently, pilots of manned aircraft are quite familiar with restricted airspace – both permanent restrictions as you describe and temporary flight restrictions (TFRs). The "No Drone Zones" are simply an extension of that concept to sUAS pilots. While the current airspace restrictions rely on a human reading and properly understanding a sectional chart or TFR, and then maintaining an accurate awareness of where they are relative to the restriction, in the future geo-fencing and GPS-based navigation can be used to eliminate this possibility for human error. Additionally, unlike hobbyist general aviation (GA) pilots today, passenger-carrying UAM aircraft will be run by professional operators who are approved to safely conduct these flights. Thus it is extremely unlikely that the situation you mention would arise. If in the highly remote instance that it did, the distributed communication and control between aircraft (as described above) and whatever human involvement there is in overseeing the activities at the test site would serve as a fall back to avoid an incident. Much like today, if a general aviation pilot were to violate a flight restricted area, there would be disciplinary consequences and the possibility of an escort flight out of the area. Again though, this is much more unlikely for UAM aircraft than for today's GA fleet.

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