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Report to Congressional Committees

May 2022

TRANSFORMING AVIATION

Stakeholders Identified Issues to Address for 'Advanced Air Mobility'

GAO-22-105020

GAO Highlights

Highlights of GAO-22-105020, a report to congressional committees

May 2022

TRANSFORMING AVIATION

Stakeholders Identified Issues to Address for 'Advanced Air Mobility'

Why GAO Did This Study

Proponents of AAM have said that services using small electrically powered aircraft that can take off and land vertically could reduce urban congestion, speed cargo delivery, and provide lifesaving medical transportation. AAM would do so by using aircraft that are intended to be simpler to design and construct, easier to fly, quieter, and less expensive to operate than traditional aircraft. However, industry stakeholders and Members of Congress have raised questions about realizing AAM's implementation, particularly in an aerospace sector that already struggles to attract and retain personnel.

The explanatory statement to the Consolidated Appropriations Act, 2021, included a provision for GAO to examine the AAM industry's workforce needs. This report describes stakeholders' views on: (1) issues in implementing widespread AAM operations; (2) challenges in developing a skilled AAM industry workforce, and (3) projected timeframes for development of the AAM industry.

GAO reviewed documents and interviewed officials from FAA, the National Aeronautics and Space Administration, and the Air Force on efforts to develop AAM operations and the industry's workforce. Further, GAO interviewed a non-generalizable sample of 36 stakeholders including AAM companies, trade organizations, standards bodies, colleges and universities, state and local governments, and organizations that represent aerospace workers on these issues.

View GAO-22-105020. For more information, contact Heather Krause at (202) 512-2834 or KrauseH@gao.gov.

What GAO Found

Small electrically powered aircraft that can take off and land vertically may soon transform the aviation market with services known as "Advanced Air Mobility" (AAM). Thirty-six stakeholders GAO interviewed described a number of issues that will need to be addressed by industry and the federal government before AAM operations can be widely implemented. Such issues include:

- **Approving new aircraft designs:** AAM aircraft incorporate many new features like electric propulsion and vertical flight capabilities that the Federal Aviation Administration's (FAA) regulations do not yet cover.
- **Fostering public acceptance of AAM:** The AAM industry will need to show that these aircraft are safe, reliable, and quiet, and that operations are commercially viable to support development and growth of the industry.
- **Developing new ground infrastructure:** Standards for developing landing facilities and the electrical infrastructure to support the large quantities of electricity needed to charge aircraft batteries have not yet been developed.

Examples of Electric Vertical Takeoff and Landing Aircraft

Sources: Beta Technologies (left) and © 2022 Wisk Aero LLC (right). | GAO-22-105020

Stakeholders also described several challenges related to the workforce needed to make the AAM industry viable. For example, pilots and maintenance technicians will have to be trained in new skills related to automation and electric propulsion. Such training would require investment in new standards and curriculums. Some stakeholders cautioned that schools may be reluctant to make such investments until AAM aircraft designs, and related federal standards are more certain. Some stakeholders also said the AAM industry could face workforce supply issues similar to those faced by the broader aerospace industry, which has struggled in recent years to recruit and retain workers. Factors affecting supply include high educational costs, a lack of workplace diversity, inadequate awareness of opportunities, and limited training capacity, according to stakeholders GAO interviewed.

Stakeholders said the pace at which the AAM industry develops will depend on how fast the industry and government address these various issues. Many forecasted the industry would begin limited operations within the next 5 years. The stakeholders suggested the scale of operations in 10 years would depend on addressing certification, and other issues, and identifying profitable markets.

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Abbreviations

AAM	Advanced air mobility
AMT	Aviation maintenance technician
eVTOL	Electric vertical takeoff and landing
FAA	Federal Aviation Administration
NASA	National Aeronautics and Space Administration
STEM	Science, technology, engineering, and mathematics
STEM AVSED	STEM Aviation and Space Education program
UAM	Urban air mobility
UAS	Uncrewed aircraft system

U.S. GOVERNMENT ACCOUNTABILITY OFFICE
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May 9, 2022

The Honorable Brian Schatz
Chair
The Honorable Susan Collins
Ranking Member
Subcommittee on Transportation, Housing and Urban Development, and Related Agencies
Committee on Appropriations
United States Senate

The Honorable David Price
Chair
The Honorable Mario Diaz-Balart
Ranking Member
Subcommittee on Transportation, Housing and Urban Development, and Related Agencies
Committee on Appropriations
House of Representatives

Small, electrically-powered, highly automated aircraft, most of which can take off and land vertically, could soon transform the aviation market. This concept, known as Advanced Air Mobility (AAM),[1] has the potential to reduce urban congestion, shorten commuting times, speed cargo delivery, and provide lifesaving medical transportation to remote areas, among other applications. Moreover, because of their electric propulsion and automated systems, these aircraft could be simpler to design and construct, easier to fly, quieter, and less expensive to operate than traditional aircraft.

However, since AAM incorporates new technologies that have not previously been used on commercial aircraft, industry stakeholders and Members of Congress have raised a range of questions about realizing the potential of the AAM industry. In particular, they have noted the challenges of developing an appropriate regulatory framework and sufficient workforce. With regard to workforce, we have previously

[1]The term Urban Air Mobility (UAM) was previously used to describe passenger services in urban areas. FAA, NASA, and stakeholders we interviewed all said that the industry is now mostly using the term Advanced Air Mobility (AAM) as a more expansive term to cover additional uses for these small, electrified, and highly automated aircraft, such as operations in less populated areas.

reported that the traditional aerospace sector already faces difficulties in attracting and retaining personnel. In addition, industry stakeholders have expressed concern that the acquisition of new skills required for this nascent industry could also be hampered by traditionally high training costs, outdated training curriculum requirements for aviation maintenance technicians, and a lack of workplace diversity.

The explanatory statement accompanying the Consolidated Appropriations Act, 2021, included a provision for GAO to conduct a study of the AAM industry's workforce needs. This report describes stakeholders' views on:

- issues the AAM industry needs to address before implementing widespread AAM operations,
- challenges in developing a skilled AAM industry workforce, and
- timelines for the AAM industry's development.

To address these objectives, we reviewed agency documents and interviewed officials from the Federal Aviation Administration (FAA); the National Aeronautics and Space Administration (NASA); and the Air Force's Agility Prime program about their respective agencies' activities related to AAM. These activities included efforts to research, test, and certificate aircraft; establish procedures for operating aircraft; and develop the AAM workforce.

We also conducted interviews with representatives of 36 AAM industry stakeholders. To identify these stakeholders, we conducted a literature search of academic journals and industry publications. Through this review, we found that much of the policy-oriented research and advocacy for AAM was being conducted by professional organizations that represent AAM companies, airports, and other industry stakeholders. In addition, we found that colleges and universities are conducting research on AAM technologies, and literature indicated that colleges and universities would provide vital training services to the AAM industry. We conducted initial interviews with aircraft manufacturers, operators, professional organizations, and state and local governments to identify additional industry stakeholders.

We divided the range of stakeholders we identified into six categories.[2] Table 1 identifies these categories and the types of stakeholders included in each category. For a complete list of AAM stakeholders we interviewed, see appendix I.

Table 1: Stakeholder Categories and Types

Stakeholder category	Stakeholder types
Advanced Air Mobility companies	Aircraft manufacturers, aircraft operators, and bodies representing these companies
Infrastructure organizations	Airports, air traffic management organizations, electrical utilities, electrical engineering consultants
Non-federal entities and standards organizations	Non-federal entities such as state and local governments and standards organizations that establish rules and standards for AAM
Aerospace workers organizations	Organizations representing aerospace workers
Travel organizations	Tourism and business travel organizations
Worker training organizations	Community colleges, universities, trade schools, and training consultants

Source: GAO, | GAO-22-105020

We developed and used a semi-structured interview tool for our stakeholder discussions. This tool covered questions about stakeholders' roles in the AAM industry; getting AAM aircraft operations certificated by FAA; and challenges in developing a sufficient workforce to support the industry. Using the information obtained from these discussions, we conducted a content analysis to identify key themes from these interviews. We identified key themes by reviewing the responses from each of the stakeholders and noting themes, ideas, and comments that more than one stakeholder expressed. Two analysts independently reviewed each interview. They compared the results of these reviews to determine if the key themes were consistent. To reconcile any differences in the reviews between the two team members, they discussed their reasoning, and together they came to an agreement, and documented those agreements as part of the analysis. Once this reconciliation was completed, the number of stakeholders raising key themes, ideas, or comments were tallied for reporting purposes.

Because the stakeholders we interviewed represented a range of organizations with differing areas of expertise, not all stakeholders provided information about each topic. In this report, we refer to a "few"

[2]These categories include those identified by the explanatory statement for the Consolidated Appropriations Act: representatives of aircraft manufacturers, aircraft operators, companies developing innovative technological solutions to manage air traffic, airports, the tourism industry, the business travel industry, electricity providers and utilities, and state and local governments

stakeholders if 20 percent or fewer of the stakeholders who provided information about a given topic expressed a particular view, “some” stakeholders if between 20 and 49 percent expressed a view, “many” stakeholders if between 50 and 69 percent expressed a view, “most” stakeholders if between 70 and 99 percent expressed a view, and “all” stakeholders if each of the relevant stakeholders expressed a particular view. In areas where not all stakeholders provided information about a topic, we specify the number of stakeholders who did provide information about that topic. However, in areas where we do not specify a number, we refer to the total group of 36 stakeholders. While the views presented in our report provide perspectives from a range of knowledgeable stakeholders, they are not generalizable.

We conducted this performance audit from February 2021 to April 2022 in accordance with generally accepted government auditing standards. These standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

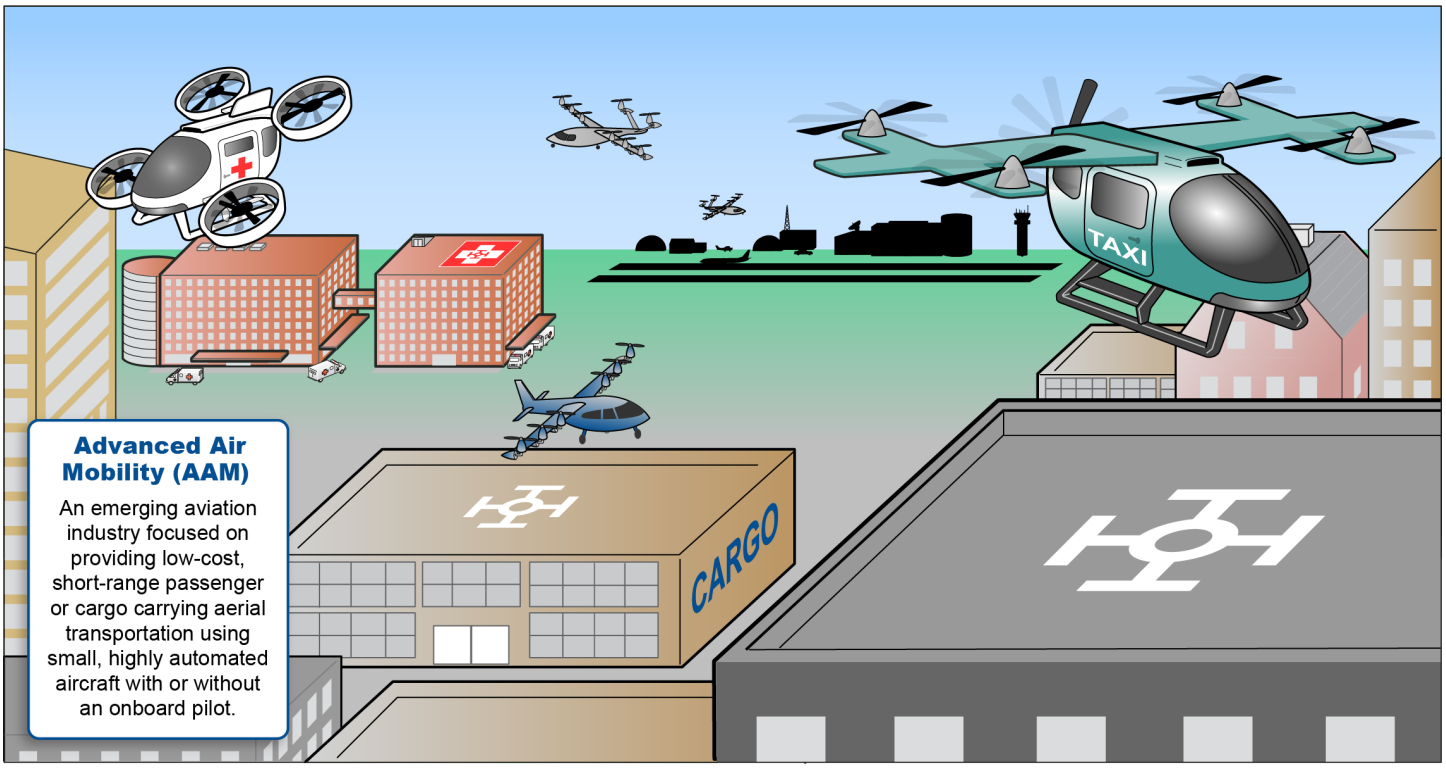
Background

Advanced Air Mobility Aircraft and Operations

Advanced Air Mobility (AAM) involves small, highly automated aircraft operating short-range passenger and cargo aviation services with or without a pilot onboard.[3] AAM operators plan to take advantage of the potential lower operating costs of electrified aircraft to allow new types of operations that would previously have been prohibitively expensive using conventionally powered aircraft such as helicopters. Such operations could include ferrying passengers through urban areas faster and more efficiently than cars, providing on-demand cargo services at logistics hubs, or transporting medical supplies to facilities in rural areas. See figure 1. As of March 2022, these aircraft have not yet entered commercial service.

[3] Highly automated operations are those that control a function or task with limited human intervention.

Figure 1: Examples of Potential Advanced Air Mobility Operations



Source: GAO. | GAO-22-105020

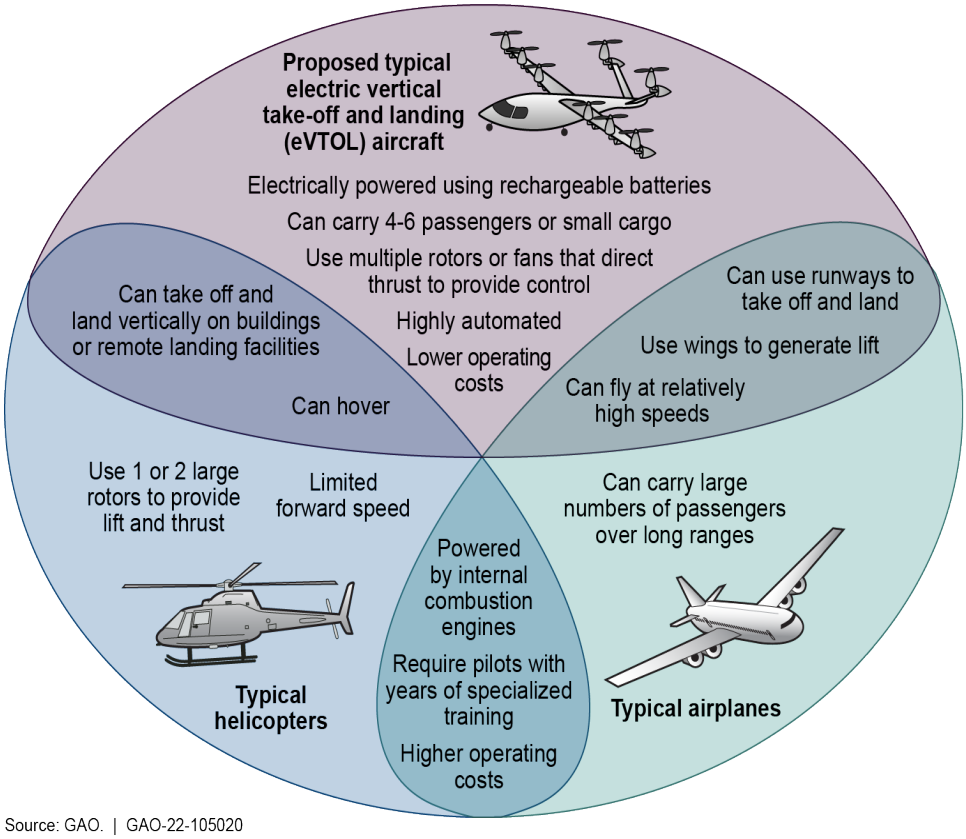
Proponents of AAM envision developing large-scale operations over time, with thousands of aircraft eventually operating in high densities across most urban areas, relieving ground-level congestion and providing low cost, high-speed cargo services. Companies that are currently invested in the AAM market include traditional aviation companies such as Bell Helicopter and Boeing, as well as new startups, such as Joby, Volocopter, and Lilium. Additionally, other companies are pursuing operations, support services, and infrastructure development for the industry. According to data compiled by the Lufthansa Innovation Hub, as of December 2021, publically disclosed global investment in the AAM sector since 2019 exceeds $7 billion.[4]

Most AAM concepts envision using electric vertical takeoff and landing (eVTOL) aircraft that will have a pilot onboard for their first operations,

[4]TNMT, Lufthansa Innovation Hub, *The Advanced Air Mobility Investment Dashboard,* accessed January 19, 2022, https://tnmt.com/infographics/advanced-air-mobility-investment-dashboard/.

with later generations of aircraft being remotely piloted. These aircraft are short-range aircraft that can take off or land vertically and have a capacity for 4-6 passengers. Most proposed eVTOL aircraft use multi-rotor designs with electric propulsion instead of internal combustion engines. These aircraft also have large degrees of automation to create aircraft that are intended to be simpler to design and construct, easier to pilot, and quieter to operate than traditional helicopters and airplanes. See figure 2. These aircraft have some basic design similarities to many smaller, multi-rotor Uncrewed Aircraft Systems (UAS) that have entered the market in recent years, including those used for aerial photography or by hobbyists. But many eVTOL designs also use a wing to provide lift in horizontal flight.

Figure 2: Shared Features of Proposed Electric Vertical Takeoff and Landing Vehicles, Helicopters, and Airplanes



Source: GAO. | GAO-22-105020

Because these new designs have characteristics of both airplanes and helicopters, they do not fit into FAA's definitions for either of those classes. In the 1990s, FAA developed a separate class of aircraft, the

'powered-lift',[5] to cover aircraft that use engine-driven lift devices such as rotors to take off and land vertically like a helicopter, but that also have wings that they can use for horizontal flight like an airplane. However, until the advent of eVTOLs, no civilian examples of this type of aircraft have entered service and the only military examples are the conventionally powered Bell Boeing V-22 Osprey tiltrotor aircraft, which entered military service in 2007, and the F-35B short takeoff and vertical landing variant, which entered service with the Marine Corps in 2015.

AAM operations using eVTOL aircraft will require significant infrastructure to take off, land, charge, load passengers and cargo, and safely navigate the national airspace system. This infrastructure includes:

- **Vertiports.** AAM proponents have proposed locating eVTOL takeoff and landing facilities—known as "vertiports"—at airports, cargo logistics hubs, and hospitals for the loading and unloading of passengers and cargo. Because eVTOL aircraft are intended to be quieter to operate than traditional aircraft, AAM companies are also proposing to locate vertiports in higher density urban environments, such as on top of parking garages or near mass transit facilities.
- **Electric charging equipment.** Since eVTOL aircraft use electricity as their energy source, AAM vertiports will require a reliable and plentiful supply of electricity to allow the aircraft to charge, along with adapter plugs to connect the aircraft to the electricity supply.
- **Air traffic management.** AAM companies are planning to operate eVTOL aircraft at lower altitudes and higher densities than traditional airplane or helicopter services. FAA is responsible for managing traffic in the national airspace system through air traffic control facilities. However, this higher density of traffic may require new technologies both on the ground and in the aircraft for controllers to identify and communicate with aircraft, and provide clearance for aircraft to use airspace, as well as for the aircraft to navigate complex environments and detect and avoid one another.

The Aerospace Workforce

[5]DOT's Fall 2021 Unified Agenda includes a Notice of Proposed Rulemaking that would remove the term powered-lift and designate applicability of current airplane operating regulations for aircraft formerly referred to as powered-lift category aircraft. DOT, *Revised Airplane Definition to Incorporate Powered-lift Operations,* RIN: 2120-AL72 (Fall 2021) https://www.reginfo.gov/public/do/eAgendaViewRule?pubId=202110&RIN=2120-AL72 .

AAM operations, as currently envisioned, will also require significant numbers of personnel to design, construct, fly, service, and maintain the aircraft. For AAM, this workforce would include:

- **Pilots:** While eVTOL aircraft used in AAM operations will be highly automated, most AAM companies say their aircraft will require an onboard pilot for their initial operations. Because AAM operations will involve transporting people or property for compensation, FAA's existing regulations require these pilots to hold at least an FAA Commercial Pilot Certificate that requires years of training and a significant financial investment. FAA requires the use of a pilot certificate specific to categories of aircraft for which a pilot has obtained a rating, such as for airplanes, rotocraft (helicopters), or gliders, because flying these various categories of aircraft require different skills. For example, flying a helicopter requires the ability to hover and maneuver vertically, whereas flying an airplane requires different skills that relate to flying horizontally. Commercial pilots are mostly trained through: (1) FAA-certificated collegiate aviation schools—typically through 2- and 4-year professional pilot degree programs at a college or university; (2) FAA-certificated non-collegiate schools; or (3) the military. For single-pilot commercial operations of the type proposed by many AAM companies, FAA regulations require pilots to have a commercial certificate and at least 500 hours of flight experience.[6]
- **Aviation Maintenance Technicians (AMT):** The current aviation maintenance technician workforce includes FAA-certificated mechanics, who are authorized to inspect aircraft and return them to service after maintenance, and non-certificated workers who can perform maintenance work under the supervision of a certificated mechanic.[7] Many technicians obtain the training and experience required for certification at FAA-approved aviation maintenance technician schools that are required to teach students a curriculum based on a set list of topics specified within FAA's regulations.[8] This curriculum covers inspection and repair items for traditional aircraft

[6]14. C.F.R. § 135.243.

[7]To become certificated, a technician must earn a mechanic certificate with an airframe rating (A), a power plant rating (P), or an airframe and powerplant rating (A&P). Because most certificated maintenance technicians have both ratings, we refer to them together. Students pursuing both ratings must either attend an FAA-certificated training program that requires 1,900 hours of instruction, or document that they have at least 30 months of practical experience. 14 C.F.R. § 147.21(b); 14 C.F.R § 65.77.

[8]14 C.F.R. §§ 147.21(c), 147.38; 14 C.F.R. pt. 147 apps. A-D.

including repair of fossil fuel-powered engines and components, airframe structures, and navigation and communication systems. It does not, however, require maintenance technician schools to cover topics for newer technologies such as electric propulsion motors and associated batteries, which will be needed by AAM maintenance technicians.

- **Engineers:** Aerospace engineers design aircraft and components, test components, and test prototypes to make sure that they function according to design. These engineers can specialize or become experts in one or more related fields such as in aerodynamics, flight mechanics, propulsion, commercial and military airplanes, remotely piloted aircraft, and spacecraft. Designing eVTOL aircraft will also require software engineers for automated flight control systems and electrical engineers for batteries and propulsion motors. According to the Bureau of Labor Statistics, aerospace engineers typically hold at least a bachelor's degree. Stakeholders representing training institutions told us that many engineers who currently specialize in vertical flight-related areas, such as eVTOL design, also have master's degrees.
- **Manufacturing and infrastructure workers:** Manufacturing workers construct eVTOL aircraft and components such as batteries, motors, and avionics. Infrastructure workers would design, build, and staff AAM landing facilities, including handling and charging the aircraft when they are on the ground.

Federal Agencies Currently Involved in AAM

Several federal agencies have roles in regulating, supporting, and developing the AAM industry and its workforce:

- **FAA** is responsible for ensuring the safety and efficiency of the U.S. aerospace system. These responsibilities include certificating aircraft and workers such as pilots and AMTs, as well as establishing requirements for operations programs and conducting continuing surveillance to ensure regulatory compliance and continued operational safety. FAA also operates the air traffic control system, which is responsible for the safe conveyance of air traffic within the national airspace system. In 2021, FAA established the AAM Integration Executive Council, which sets objectives and oversees communication across FAA offices for initiatives related to FAA aircraft certification, ground infrastructure development, airspace integration, and operations certification. FAA also has a limited role in promoting the development of the aerospace workforce, as accomplished largely through programs for building awareness of aerospace careers.

- **NASA**, through its Aeronautics Research Mission Directorate, conducts research to help develop emerging aviation technologies, such as AAM, including aviation safety, airspace integration, automation, and noise. This work includes NASA's AAM National Campaign, an initiative to increase public confidence in AAM safety and promote industry collaboration, and AAM projects related to airspace management and vertical lift flight technology.[9] Since 2011, NASA has also provided funding for Vertical Lift Research Centers of Excellence, which are universities that conduct research on vertical flight topics and train engineers that specialize in vertical flight aircraft design.[10]
- **The U.S. Air Force**, through its Agility Prime program launched in April 2020, is working to assist the development of the commercial AAM industry in the United States to ensure a strong industrial base for these aircraft and reduce the national security risks of another country dominating the market. To accomplish these objectives, the program is partnering with multiple companies, including conducting test flights with four AAM companies as of January 2022 to validate the performance and operating costs of their aircraft, as well as to evaluate potential military missions for the aircraft, such as transporting equipment and personnel. Agility Prime also includes efforts to develop and inform pilot and maintenance training and establish operating standards for AAM.

Stakeholders Identified Certificated Aircraft, Public Acceptance, and New Infrastructure as Necessary for Widespread AAM Operations

To date, the AAM industry has been largely focused on designing, building, and certificating eVTOL aircraft. However, stakeholders we spoke with said that the new technologies these aircraft use may pose difficulties for certificating them. In addition, they said that before widespread operations the industry would need to gain the public's acceptance by showing that AAM operations are as safe, reliable, quiet and equitable as the industry has proposed. Stakeholders also said that the industry will also need to develop and finance necessary ground infrastructure such as landing facilities and electric charging equipment, and develop new concepts for airspace management to integrate high-density operations into congested airspace.

[9] The AAM National Campaign began in 2019 as the UAM Grand Challenge. NASA renamed the program in 2020 to better reflect the industry's current approach.

[10] The Vertical Lift Research Centers of Excellence program is a continuation of the U.S. Army's Center for Education and Research in Rotary Wing Aviation Technology program that began in 1982.

New Technologies Present Challenges for Certification

FAA and NASA officials, along with many of the stakeholders we spoke to, said that much work remains in order to certificate eVTOL aircraft for commercial service.[11] As of March 2022, most of the companies that have publically announced how they plan to approach certification have said that they will seek certification of their aircraft as "normal category" airplanes using the FAA airworthiness standards for these aircraft outlined in 14 C.F.R. Part 23 (Part 23).[12] This process involves FAA and the manufacturer first coming to an agreement about the certification basis and means of compliance for the aircraft (i.e., the specific standards used to meet the regulations), and how the manufacturer will show their aircraft meets those standards. Then, the manufacturer tests the aircraft and shares the testing data with FAA before FAA issues a certificate, after all agreed-upon certification requirements have been met.[13] As of January 2022, three companies have entered into certification basis agreements with FAA.

Stakeholders said that because eVTOL aircraft incorporate many new characteristics for airplanes—such as vertical flight capabilities, electric propulsion, batteries for primary energy storage, and highly automated flight control systems, among other innovations—FAA's Part 23 regulations and existing industry standards do not apply to all areas of the aircraft. This makes certificating these aircraft challenging. For example, most eVTOL aircraft combine characteristics of traditional airplanes and helicopters with the ability to operate in both horizontal and vertical flight, while FAA's Part 23 regulations cover only airplanes, which fly

[11]Twenty-five stakeholders identified aircraft certification as an issue that remains to be resolved prior to the widespread adoption of AAM services.

[12]Normal category airplanes are those with a maximum takeoff weight of 19,000 pounds or less and carrying 19 or fewer passengers. FAA recently updated the Part 23 regulations to be less prescriptive and to instead contain performance-based regulations that allow aircraft manufacturers greater flexibility for aircraft design, including alternative types of propulsion.

[13]In 2020 we identified challenges that have led to delays and difficulties for staff and applicants in FAA's update to the Part 23 regulations. We recommended, among other things, FAA provide additional information to its certification staff on the use of consensus standards and documenting means of compliance, and to develop a method to track certification projects by certification basis. GAO, *Aviation Certification: FAA Needs to Strengthen Its Design Review Process for Small Airplanes*, GAO-21-85, (Washington, D.C.: Nov. 16, 2020).

horizontally.[14] In order to control these aircraft, AAM companies have designed complex and highly automated flight control software that moderates the power produced by the aircraft's engines to control the aircraft, as opposed to the traditional aerodynamic flight control surfaces used by most small aircraft. FAA officials told us that Part 23 may not adequately account for many of these designs. In addition, Part 23's regulations describe carrying fuel to power the aircraft's engines, while many AAM companies are designing eVTOL aircraft that would use batteries. Batteries have different properties from fuel tanks and require different considerations for structural support, fire safety, and heat dissipation. These conditions are not explicitly covered under Part 23.

One AAM Industry Stakeholder's Perspective
"Certifying eVTOL aircraft is a challenge for the industry simply because it has never been done before, but FAA's use of Part 23 to do so gives companies some certainty for the process."

Source: GAO Interviews with Selected Advanced Air Mobility Industry Stakeholders. | GAO-22-105020

To meet these challenges, FAA officials said that the agency plans to certificate these aircraft using either of two processes that it typically uses for aircraft that do not fit into the regulations for an existing class of aircraft. The first would be to certificate the aircraft as a normal category airplane under part 23 but with special conditions—regulations that only apply to a particular aircraft design—that would cover the aircraft design elements, such as vertical flight capabilities, that part 23 does not cover.[15]

The second potential certification process would be to use a combination of existing regulations and additional airworthiness criteria to establish a

[14]FAA defines an airplane in 14 CFR § 1.1 as "an engine-driven fixed-wing aircraft heavier than air, that is supported in flight by the dynamic reaction of the air against its wings". We interpret this definition to refer to an aircraft that flies horizontally to obtain lift, as opposed to an aircraft that uses a spinning rotor (or other device) to obtain lift, which we interpret as an aircraft that can fly vertically.

[15]FAA uses special conditions if FAA finds that the airworthiness regulations do not contain adequate or appropriate safety standards for an aircraft, aircraft engine, or propeller because of a novel or unusual design feature. 14 C.F.R. § 21.16. To receive a special condition, an individual or entity must petition for exemption asking for relief from the current regulation. 14 C.F.R. § 11.15. FAA must then find that the special condition has safety standards with an equivalent level of safety to the regulations. 14 C.F.R. § 21.16.

'special' class of aircraft.[16] FAA has used this process for classes of aircraft for which FAA has not issued specific airworthiness standards, such as UAS and powered-lift. To use this process, FAA officials told us they would base the standards for eVTOL aircraft on the portions of Part 23 that are applicable to these designs. However, for the aircraft elements that do not fall under Part 23, FAA would use the relevant portions of other FAA regulations covering, for example, helicopters to establish requirements for eVTOLs. Finally, for the aircraft elements that do not fit any existing FAA regulations, officials said that FAA plans to work with the manufacturers to develop additional airworthiness criteria that apply only to a particular aircraft design but still provide an equivalent level of safety as FAA's regulations.

Officials said that FAA has routinely used these approaches to certificate aircraft with new technologies, and FAA would use the process most appropriate for each individual aircraft under consideration. For example, using the process for an existing class of aircraft with special conditions, in 2021 FAA established certification standards against which to evaluate one company's design for electric aircraft engines in areas such as engine control systems, fire protection, and cooling for which FAA determined that its existing regulations for engines did not contain adequate or appropriate safety standards.[17] As an example of additional airworthiness criteria for special classes of aircraft, in 2020 FAA published proposed airworthiness criteria for a small UAS designed to deliver packages. FAA based some of the proposed criteria on its existing regulations for airplanes and helicopters in areas including software, flight manuals, and handling adverse weather conditions, but also developed new criteria in areas such as the remote aircraft controls where its existing regulations did not directly apply to that particular aircraft.[18] FAA officials said they plan to continue using these processes to certificate

[16]Examples of special classes of aircraft include gliders, airships, and powered-lift aircraft. For these types of aircraft, FAA sets airworthiness standards based on the appropriate standards in its regulations for any classes of aircraft (e.g. airplanes, rotorcraft, etc.), along with additional standards not included in FAA's regulations that FAA determines will provide an equivalent level of safety. FAA refers to these additional standards as additional airworthiness criteria. 14 C.F.R. § 21.17(b).

[17]*Special Conditions: magniX USA, Inc., magni350 and magni650 Model Engines; Electric Engine Airworthiness Standards*, 86 Fed. Reg.53508 (Sept. 27, 2021).

[18]*Airworthiness Criteria: Special Class Airworthiness Criteria for the Flytrex, Inc. FTX–M600P*, 85 Fed. Reg.74622 (November 23, 2020).

eVTOL aircraft until sufficient numbers of these aircraft exist to merit developing regulations for them as a new class of aircraft.

To support certification of their aircraft designs, several companies have designed, built and flown full-scale prototypes of eVTOL aircraft. In addition, NASA, the Air Force, and other organizations are also performing research to contribute to developing and certificating eVTOL aircraft. NASA officials said their agency contributes research and testing data, as well as expertise, to the development of standards for certificating aircraft and aircraft components. For example, they said NASA will share the testing data from the AAM National Campaign with FAA and standards bodies such as ASTM international and RTCA, to help develop standards that industry and FAA can use to certificate eVTOL aircraft.[19] NASA also plans to conduct its first full-scale tests as part of its AAM National Campaign in 2022 and conduct more advanced tests—including tests of remotely piloted aircraft—in 2023. In 2021, the Air Force awarded its first airworthiness approval for crewed flights using eVTOL aircraft. Officials told us that they plan on using the information from the test program to establish airworthiness standards and evaluate potential military uses of eVTOL aircraft.

AAM Industry Will Need Public Acceptance to Succeed

FAA and NASA officials, and many of the stakeholders we spoke with, said that for the AAM industry to succeed, it will need to convince the public that AAM operations are safe, reliable, quiet, and equitable.[20] For example, many of the stakeholders who discussed community engagement identified getting the public to accept the noise produced by eVTOL aircraft as a key remaining obstacle for the AAM industry. They said that the AAM industry is planning operations such as urban air taxis, which are planned to take place in closer proximity to homes, neighborhoods, and businesses than traditional aviation services, and which will require greater consideration for noise. In 2021 we reported that noise from helicopters—the aircraft with flight profiles most similar to eVTOL aircraft—can expose the public to a variety of potentially negative

[19]Consensus standards are technical specifications developed by organizations such as RTCA and ASTM International, internationally recognized standards-development organizations. In 2019 ASTM International introduced a technical committee to coordinate industry efforts to identify and address gaps in certification standards for eVTOL aircraft. As of 2021, this group was conducting work on AAM topics such as electric propulsion, remote identification, information security, and infrastructure.

[20]Twenty-eight stakeholders we spoke with identified community engagement as an issue that remains to be resolved prior to the widespread adoption of AAM services.

effects, ranging from annoyance to more serious medical problems such as sleep disruptions and cardiovascular disease.[21] Although AAM companies have stated that the electric motors used on eVTOL aircraft are significantly quieter than traditional internal combustion engines, these aircraft will still have rapidly spinning propellers, and it is not yet known how much noise they will produce. In addition, some stakeholders identified public perceptions regarding the safety of eVTOL aircraft as vital to community acceptance. They noted that the public has never seen these aircraft in operation, and acceptance of large numbers operating in close proximity to people and buildings will require a concerted effort on the part of industry and government to show these aircraft's safety by demonstrating safe, reliable operations.

One AAM Industry Stakeholder's Perspective

"The public has yet to embrace a future that includes AAM systems or services. The industry will need to continue to develop important partnerships with communities, as well as demonstrate the capabilities and safety of AAM systems, in order to achieve public appreciation and demand for the new capability."

Source: GAO Interviews with Selected Advanced Air Mobility Industry Stakeholders. | GAO-22-105020

Also, a few other stakeholders said that to avoid a public perception of AAM services as a luxury item for the wealthy, the AAM industry must engage with local stakeholders to ensure that services are integrated with other local transportation options and located to ensure equitable access to services and exposure to adverse effects. While AAM operations can potentially complement existing transportation services, stakeholders said that providers need to work closely with local officials to ensure that AAM is integral to a transportation system as opposed to a standalone service. In addition, some stakeholders expressed concern that without proper coordination, traditionally underserved neighborhoods could be left out of AAM services and benefits, while bearing the brunt of proximity and dislocation, as has often been the case with highway construction.

Stakeholders suggested a number of ways for the industry and federal government to work with communities to improve the public's perception of AAM operations. First, they said that demonstrating safe, reliable, and beneficial operations early on would be important to developing public

[21]GAO, *Aircraft Noise: Better Information Sharing Could Improve Responses to Washington, D.C. Area Helicopter Noise Concerns*, GAO-21-200 (Washington, D.C.: Jan. 7, 2021).

trust in AAM. Some stakeholders suggested giving early priority to medical and public service operations, such as evacuations, air ambulance, and transport of medical equipment to show the benefits of AAM while also demonstrating the safety and reliability of services. Others suggested FAA help the AAM industry engage with the community. We have found that such an approach can bolster public acceptance in areas such as airspace redesigns in various large metro areas. Specifically, we reported in 2021 that in 2013 and 2014 FAA only consulted with local airport officials before implementing significant changes to local area flight patterns, known as "metroplex" projects. This approach resulted in community concerns not being addressed and litigation.[22] Since the initial metroplex projects, FAA has expanded its outreach to include briefings for local elected officials, public workshops, and the development of a community involvement plan for each project.

Stakeholders we spoke with said that FAA's expanded outreach could be a model for how FAA can approach integration of AAM operations into local areas. Nevertheless, in 2021, we found that FAA could still improve its guidance for how it engages with communities before and after it implements a change.[23] Regarding AAM development, FAA officials agreed that the strategy used in those projects could be a useful model for community engagement. They added that FAA also plans to use the offices of its regional administrators to leverage existing relationships with local associations and other groups as the agency develops plans for integrating AAM operations.

Stakeholders Said Ground Infrastructure Will Require Financing, Standards, and Local Coordination

AAM operations will require many different kinds of ground infrastructure, and many stakeholders we interviewed said that these facilities have yet to be developed.[24] This infrastructure includes vertiports, passenger handling equipment, and electrical equipment for charging eVTOL aircraft. Stakeholders said that before AAM companies can begin the kinds of high-density operations required for their business models,

[22]GAO, *Aircraft Noise: FAA Could Improve Outreach through Enhanced Noise Metrics, Communication, and Support to Communities*, GAO-21-103933 (Washington, D.C.: Sept. 28, 2021).

[23]We recommended that FAA, among other things, update its community engagement guidance to incorporate additional communications tools and provide clearer information to airports and communities on what communities can expect from FAA after implementation of certain changes. FAA concurred with these recommendations and plans to update its guidance on community outreach by the end of 2022.

[24]Twenty-five stakeholders we spoke with identified infrastructure development as an issue that remains to be resolved prior to the widespread adoption of AAM services

ground infrastructure to support operations needs to be in place. However, while AAM proponents have described using currently existing urban parking garages, building roofs, and mass transit stations as vertiports, these facilities would require extensive modifications to make them useful for AAM. As of March 2022, no AAM-specific ground infrastructure has been put into operation. Stakeholders also said that it remains unclear how the ground infrastructure will be financed, whether landing facilities will be for public use or limited to private operators, and what the construction and operations standards for these facilities will be.[25] They also said that infrastructure developers may be hesitant to finance AAM projects until the industry demonstrates its viability.

Electrical infrastructure for AAM is another area that stakeholders said will require a substantial amount of additional development. Because most eVTOL aircraft are electrically powered, stakeholders said they will require large quantities of electricity to charge their batteries. Stakeholders expressed concern that providing this electricity to landing facilities could be a challenge since the U.S. electrical grid is operated and regulated by a variety of utilities, state agencies, local governments, and cooperatives. Therefore, most electrical infrastructure projects require financing and regulatory approval from multiple entities, taking multiple years to plan and execute. Additionally, they said that in certain areas the time of day, frequency, and rate of eVTOL aircraft charging that AAM companies may require for their operations could consume enough electricity to impact the electrical grid and require additional investments by electric utilities—further delaying AAM infrastructure development. Some stakeholders also mentioned the need to develop standards for aircraft chargers that would be used to connect the aircraft to the electrical grid to avoid similar compatibility issues as the surface electric vehicle industry.

One AAM Industry Stakeholder's Perspective

"Fast charging multiple eVTOLs at the same time (like would be required for high density, quick-turnaround operations) will require megawatts of power to be delivered to vertiports… Developing the necessary electrical standards and infrastructure are major requirements for AAM services to scale up past the initial stages."

Source: GAO Interviews with Selected Advanced Air Mobility Industry Stakeholders. | GAO-22-105020

[25] GAO is currently reviewing the current and potential future costs of AAM ground infrastructure, as well as the costs of FAA's efforts to support safe AAM travel within the national airspace.

Stakeholders and FAA officials said that a lack of standards for vertiports is another challenge for locating and designing AAM infrastructure. They said that vertiports will require different standards than traditional helicopter or airplane facilities because eVTOL aircraft use different power sources than both traditional airplanes and helicopters and may have different performance characteristics. For their part, FAA officials said that while FAA has existing standards and guidance for helicopter landing facilities, eVTOL aircraft may have different design and performance characteristics and require different equipment such as specialized firefighting equipment for battery fires. Consequently, FAA is working on developing an advisory circular on vertiport design for publication in 2024. In the interim, in February 2022 FAA released a draft engineering brief on vertiport design that covers safety-critical vertiport elements such as landing area size and lighting. FAA plans to release the final version of this brief in the summer of 2022.

Stakeholders Said Government and Industry Will Need to Develop New Concepts for Airspace Management

Many AAM proponents envision high-density operations in congested urban airspace, and some stakeholders we spoke with said that developing ways to integrate these operations into the national airspace system will need to be done before this can happen.[26] The AAM companies that have publically announced their plans for initial operations have stated that they will begin operations under existing 'visual flight rules' that in certain conditions allow pilots to self-maintain separation from other aircraft provided that weather conditions such as flight visibility are above certain standards. However, in practice operations using these rules allow for limited numbers of aircraft, and AAM operators plan to become larger in scale to include many aircraft and expand in geographic reach to include areas of the country that more frequently experience low visibilities that preclude the use of visual flight rules. Therefore, most stakeholders agreed that for AAM operations to be successful, FAA would need to develop new rules and procedures to allow higher densities of aircraft in more types of weather.

One AAM Industry Stakeholder's Perspective

"The key to any automated and/or beyond visual line of sight operations will be the successful development of highly effective and safe 'detect and avoid' technology. This will continue to be one of the highest priorities as the AAM industry continues to develop."

Source: GAO Interviews with Selected Advanced Air Mobility Industry Stakeholders. | GAO-22-105020

[26]Sixteen stakeholders we spoke with identified airspace management as an issue that remains to be resolved prior to the widespread adoption of AAM services.

Both FAA and NASA officials said that their agencies have been collaborating to develop new concepts for traffic management systems for uncrewed or remotely-piloted aircraft that could apply to AAM. In 2020, both released "concept of operations" documents that laid out what AAM operations in urban areas could look like at different stages of the industry's development.[27] FAA's document envisioned three phases of development: (1) initial operations using the current regulatory environment, (2) more developed operations using established voluntary "corridors" for AAM traffic,[28] and (3) a mature state of development using highly automated traffic management solutions that would enable high densities of remotely piloted aircraft. NASA's corresponding document describes a vision for AAM at a higher level of maturity and delineates some of the technologies and rules that would be needed for high-density AAM operations and traffic management solutions for UAS operations, a concept known as UAS traffic management. These technologies include a highly automated air traffic control system, micro-scale weather sensing and forecasting, resilient communications, and operations planning. The document envisions that many of these services could be provided by third-party companies operating under FAA's authorization to provide information sharing between AAM operators, the aircraft themselves, and FAA's air traffic control system.

FAA officials described this concept of operations document as an initial notion of how FAA and industry may manage AAM traffic in urban areas. These officials said that the agency is working with industry to develop an updated version of the document to be released in 2022. For this next version, they said they are working on more details about how AAM corridors, if established, would work, including where corridors could potentially be located, what the requirements might be for using a corridor, what the aircraft separation standards could be inside the corridors, and other topics. Ultimately, they said that establishing AAM-specific airspace and operating requirements would depend on what types of operations the industry actually develops and the demand for these services. NASA officials, meanwhile, said that traffic management

[27]Federal Aviation Administration, *Urban Air Mobility: Concept of Operations, v1.0*, (Washington, D.C.), June 26, 2020, and NASA (prepared by Deloitte Consulting, LLP), *UAM Vision Concept of Operations: UAM Maturity Level 4*, (Washington, D.C.) December 2, 2020.

[28]FAA defines an AAM 'corridor' as a defined geographic area within FAA's controlled airspace where AAM services could operate without the need for traditional air traffic control services and would instead rely on a set of technologies for AAM aircraft that would allow the aircraft to navigate and maintain appropriate separation from one another.

will remain one of the agency's most important areas of focus for research, including understanding how technologies that are developed for UAS traffic management can be used to manage AAM traffic. Both NASA and FAA officials said that their agencies are collaborating on traffic management systems developed for UAS that could apply to AAM.

Since most AAM companies are planning to eventually operate remotely piloted aircraft, some stakeholders drew similarities between the need to manage AAM traffic and industry's efforts to develop UAS traffic management solutions. Stakeholders said that integrating both AAM operations and UAS traffic would require a number of innovative technologies and changes to FAA's operating rules. For example, in 2021 we reported that successful integration of remotely piloted aircraft into the national airspace system will require aircraft to utilize new technologies. These include technologies that allow aircraft to maintain a safe distance from one another and maintain a communications link to the operator. Successful integration of these aircraft would require rule changes and technological adaptation for remotely identifying aircraft without a pilot on board.[29]

Stakeholders Cited the Need for a Newly-skilled Workforce amid Longstanding Challenges with Workforce Availability and Recruitment

Stakeholders we spoke with said that designing, operating, maintaining, and servicing eVTOL aircraft will require the AAM workforce to be trained in new skills, including those related to electric propulsion and highly automated operations. In addition, they said that the AAM industry will need to compete for skilled workers with other industries, including other aerospace sectors, and may face similar longstanding challenges recruiting and retaining workers. They also described challenges in training sufficient numbers of workers and developing standards and curriculums to cover the new skills needed for AAM.

The AAM Workforce Will Need Training for New Skills in Electrification and Automation, according to Stakeholders

Because eVTOL aircraft incorporate a number of new technologies that have not been previously used on commercial aircraft, workers for this industry will need to have a number of new skills to design, operate, maintain, and service eVTOL aircraft. Stakeholders told us that while the various AAM occupations will still require many of the same skills as traditional aerospace careers, many of these new skills, particularly those

[29]GAO, *Unmanned Aircraft Systems: FAA Could Strengthen Its Implementation of a Drone Traffic Management System by Improving Communication and Measuring Performance*, GAO-21-165, (Washington, D.C., Jan. 28, 2021).

related to electrification and highly automated flight control systems, are not yet taught at most aerospace training facilities.

Pilots

Many of the stakeholders we spoke with said that early AAM pilots will need not only traditional flight skills but also skills for monitoring the sophisticated computer systems of highly automated aircraft operations.[30] These include controlling the aircraft safely within existing airspace given various weather and traffic management constraints, while managing complex aircraft systems.

Because eVTOL aircraft require new flight skills, stakeholders and FAA officials told us that FAA would need to develop new training and certification standards for pilots. Since many eVTOL aircraft are able to fly horizontally like an airplane and take off and land vertically like a helicopter, some stakeholders emphasized that eVTOL pilots will need to be skilled in controlling the aircraft in both of these flight modes. These are distinct enough skills that FAA has traditionally required pilots to have separate certificate category ratings for airplanes and helicopters, and developed a separate 'powered-lift' category rating for aircraft that have combinations of these characteristics, discussed below.[31]

Many companies that are designing eVTOL aircraft are trying to address the need for pilot skills in multiple flight modes by developing these aircraft with highly automated flight control systems, often known as Simplified Vehicle Operations. Many of the stakeholders we spoke with said that eVTOL pilots would require specific skills in managing these highly automated systems. For example, they said that the automated systems will change the pilot's interface with the aircraft from the conventional interface in which the pilot controls the aircraft by directly manipulating its control mechanisms to one of inputting flight instructions into a computer which decides how to manipulate the aircraft's control mechanisms to execute the instructions provided by the pilot. Five stakeholders suggested that because Simplified Vehicle Operations could automate many traditional flying tasks, FAA could reduce some

[30]Twenty-five stakeholders provided information about the knowledge and skills that AAM pilots will need.

[31]To obtain a commercial pilot certificate with an airplane class rating, a pilot must have at least 250 total hours of flight experience, with requirements for specific types of flight time, including that 50 hours must be in airplanes. 14 C.F.R. § 61.129(a)-(b). For a commercial pilot with a helicopter class rating, a pilot must have at least 150 total hours of flight experience, with requirements for specific types of flight time, including that 50 hours must be in helicopters, see 14 C.F.R. § 61.129(c).

knowledge and skill requirements for commercial pilot certification and thereby could lower training costs. However, three stakeholders disagreed and maintained that for safety reasons, FAA should maintain the same training and experience standards for eVTOL pilots.

In addition to operating different flight controls, some other stakeholders said that eVTOL pilots would need skills for managing electric power systems and batteries. They noted, for example, that eVTOL pilots would need to know how to monitor battery charge levels and the health of battery systems along with electric motor temperatures and control mechanisms, which are different from managing fuel tanks and engines. A few stakeholders commented that navigating in the potentially congested airspace of urban environments and ferrying passengers in close quarter cabins would also demand additional pilot skills.

To inform decisions on what skills and experience eVTOL pilots will need, in 2021 the Air Force began developing a study on training eVTOL pilots that will compare training results using recent graduates of initial pilot training against new service members who have not previously flown. Officials said that they plan to use the results of this study to develop training and experience standards for military eVTOL pilots. FAA officials said that they are collaborating with the Air Force on this study and plan to use the results, along with information from FAA's own research activities, as the agency defines the necessary skills and experience for eVTOL pilots.

One AAM Industry Stakeholder's Perspective
"In the short term, the aircraft will be piloted as there is currently no path to certification of autonomous aircraft through the FAA."

Source: GAO Interviews with Selected Advanced Air Mobility Industry Stakeholders. | GAO-22-105020

Aviation Maintenance Technicians

Many of the stakeholders we spoke with told us that AAM operations would require AMTs to have new skills specific to eVTOL aircraft.[32] For example, all of these stakeholders concurred that skills related to electrification will be important for maintenance technicians. They noted, for example, that eVTOL aircraft batteries and electric motors will operate at high voltages and will require maintenance technicians to understand how to safely work with high voltage equipment, which is not typically used on traditional aircraft. In addition, they said that AMTs will need to understand propulsion battery design and temperature management.

[32]Twenty-four stakeholders provided information about the knowledge and skills needed by Aviation Maintenance Technicians.

Also, because they have fewer moving parts such as pumps for lubricants and fuel, maintenance of these electrified components may be able to take place with the parts detached from the aircraft. As a result, technicians would detach and reattach more motors and other components than is the case for current aircraft.

One AAM Industry Stakeholder's Perspective
"Traditional maintenance skills such as repairing fossil fuel powered engines and sheet metal work will be less needed, but eVTOL maintenance technicians will need to know how to work on composites, batteries, electric motors, and advanced electric power control systems, which are not skills that current aircraft mechanics use all that much."

Source: GAO Interviews with Selected Advanced Air Mobility Industry Stakeholders. | GAO-22-105020

In addition to understanding the electric power systems, a few stakeholders said that because eVTOL aircraft will not be made out of traditional aluminum, maintenance technicians for AAM operations would need new knowledge to work on structures made of advanced composite materials. While the traditional aerospace industry has been using more composite materials in recent decades to save weight, stakeholders suggested that eVTOL aircraft may incorporate batteries and other systems into the structure of the aircraft itself in ways that traditional aircraft have not yet done. Some stakeholders added that these technicians would also need additional software skills to troubleshoot the computer-controlled systems of the highly automated eVTOL aircraft.

Engineers

According to some of the stakeholders we interviewed, eVTOL aircraft design draws from a wider range of engineering disciplines than traditional aerospace design work, particularly with regard to software, electrical, and chemical engineering.[33] Engineers who work in the AAM industry must, therefore, be able to synthesize information from these different disciplines. For example, many of these stakeholders told us that AAM engineers will need to design new types of electric power systems, including batteries, motors, and control systems. In particular, AAM companies will need to design batteries that are optimized for the charge and discharge cycles that rapid aviation operations will require, in contrast to the cycles required by automotive or other applications.

[33]Fifteen stakeholders provided information about the knowledge and skills needed by aerospace engineers.

One AAM Industry Stakeholder's Perspective
"Engineering eVTOL vehicles requires a number of different disciplinary practitioners working together, including aircraft designers, aerodynamicists, battery experts, avionics engineers, acoustics engineers, systems engineers, and others."

Source: GAO Interviews with Selected Advanced Air Mobility Industry Stakeholders. | GAO-22-105020

Additionally, some stakeholders, particularly those involved in teaching aerospace engineers, emphasized the differences between designing traditional airplanes and aircraft capable of vertical flight, such as eVTOLs. For example, this means understanding vibrations, acoustics, and complex aerodynamic interactions between sets of tilting rotors. They said that these skills are not generally taught in traditional aerospace engineering programs. Some also said that engineers for eVTOL aircraft would need extensive software skills to design the complicated flight control systems used by these aircraft, since companies building them are using more machine learning and artificial intelligence applications in their designs.

Manufacturing and Infrastructure Workers

Some stakeholders we spoke with said that workers who work in AAM manufacturing and the design and operation of AAM ground infrastructure would need new skills related to constructing eVTOL aircraft and providing ground support services.[34] For example, most of these stakeholders said that AAM manufacturing workers would need skills related to advanced manufacturing techniques, such as additive manufacturing, robotics, and composite material curing.[35] Stakeholders added that traditional aerospace manufacturers make smaller numbers of airplanes per month than AAM companies are proposing to produce. Such a volume would necessitate different manufacturing techniques. A few stakeholders noted that these techniques may be similar to those used by the automotive industry. Also, some of these stakeholders noted that because AAM infrastructure has not been developed, the industry would need workers who have the skills to design and construct it. They

[34]Eleven stakeholders provided information about the skills required by AAM manufacturing workers, and nine provided information about AAM infrastructure workers. NASA officials also noted the need for workers to have skills related to building manufacturing supply chains for AAM-related systems and parts.

[35]Additive manufacturing, also known as 3-D printing, is a layer-by-layer process of producing 3D objects directly from a digital model. This process differs from conventional manufacturing techniques, which create a part or product by cutting away material from a larger piece. Composite materials are produced by combining layers of carbon or glass fibers with epoxy.

also said that once the infrastructure is in operation, workers will need to have skills for using electric charging equipment and any other equipment needed to handle the aircraft on the ground.[36]

The AAM industry Would Compete with Existing Industries for Workers with Critical Skill Sets

Stakeholders we interviewed stated that some existing workforce needs are already in short supply in the aerospace industry. This lack of supply could be a major challenge to the development of the AAM industry. Stakeholders cited problems of high training costs and a traditionally narrow pipeline of recruitment resulting in both a lack of workforce diversity and sufficient awareness of the opportunities afforded by the industry.

Over the past 5 years, we have reported that the aerospace industry has faced difficulties acquiring sufficient numbers of qualified pilots and aviation maintenance technicians, and stakeholders we spoke with for this report told us that they anticipate these challenges may become worse in the future. For example, in 2018, we reported that regional airlines said they had begun to reduce flights and eliminate routes due to a lack of pilots. In early 2020, we reported that industry stakeholders were concerned over the capacity of the aviation maintenance workforce to meet projected needs due to retirements, attrition, fleet growth, and the growing demand for air travel.[37] Many stakeholders we spoke with echoed these concerns, saying that current demand exceeds the number of students in these fields. They also said that AAM operations may create additional demand, exacerbating difficulties in acquiring enough workers and challenging the development of the AAM industry.

High Educational Costs

Affordability is an important factor affecting the potential pool of applicants for aerospace professions. Stakeholders noted that the high cost of aerospace education limits access to employment opportunities in the

[36]FAA officials also suggested the need for AAM companies to employ air traffic management workers who would provide traffic management, flight planning and weather services.

[37]GAO, *Collegiate Aviation Schools: Stakeholders' Views on Challenges for Initial Pilot Training Programs*, GAO-18-403 (Washington, D.C.: May 15, 2018) and GAO, *Aviation Maintenance: Additional Coordination and Data Could Advance FAA Efforts to Promote a Robust, Diverse Workforce*, GAO-20-206 (Washington, D.C.: Feb. 6, 2020). In addition, GAO is conducting separate work examining the future supply and demand for pilots and aviation maintenance technicians, including the effects of the COVID-19 pandemic. To obtain a commercial pilot certificate with a powered-lift category rating, a pilot must have at least 250 total hours of flight experience, with requirements for specific types of flight time, including that 50 hours must be in powered-lift aircraft, see 14 C.F.R. § 61.129(e).

AAM industry as well as the aerospace industry in general. Some said that the high costs of training for some aerospace professions particularly acts as a barrier to entry for students who are not from affluent backgrounds. In 2018, we reported that high costs—at least $50,000 total—were one of the major challenges facing pilot training programs in recruiting and retaining students.[38] Stakeholders we interviewed reiterated that potential students choose not to pursue aerospace education because of these high costs.

Stakeholders suggested several potential ways for the AAM industry and federal government to alleviate the high costs of education as a barrier to entry into the AAM workforce. Some emphasized the need to provide sufficient funding for education that will train AAM workers and to provide financial assistance programs for students. Specifically, they suggested providing financial support to students pursuing technical training for AAM. Additionally, one suggested that making flight training eligible for federal student loans could make it easier for students to complete flight training and could help alleviate the shortfall of pilots. In 2018, we also reported that some stakeholders in the collegiate flight training sector suggested that increasing the limits on federal student loans could help students complete training by providing them with additional resources to help pay for flight training costs.[39]

Moreover, stakeholders who represented training facilities for engineers noted that while many engineering graduate students will have their tuition covered by grants and other agreements, the universities bear extensive costs to train them. The Vertical Lift Research Centers of Excellence program administered by NASA and the Department of Defense helps alleviate this problem by providing funding to universities that train vertical flight engineers. However, funding for this program has remained unchanged in recent years, and officials from those programs told us the increasing cost of education has reduced the number of students they are able to train. NASA officials told us that they view the program as a valuable addition to the agency's research and workforce development objectives because it increases the number of engineers these universities are able to train. However, they said current funding for the program does not support enough students to meet the industry's expected needs. In 2021, the same three universities that received

[38]GAO-18-403

[39]GAO-18-403

funding in the previous funding cycle had their places renewed in the program for five more years.

One AAM Industry Stakeholder's Perspective
"It costs more than $100,000 per year to train a vertical lift engineering graduate student, and the cost is going up every year."

Source: GAO Interviews with Selected Advanced Air Mobility Industry Stakeholders. | GAO-22-105020

Lack of Workforce Diversity and Awareness of Opportunities

With the aerospace industry facing worker availability challenges in key professions, some stakeholders noted an industrywide failure to cultivate a more diverse workforce as a factor in these hiring shortfalls and said that the AAM sector also reflects a similar deficiency in recruitment and retention of workers from traditionally underrepresented groups. These stakeholders said the aerospace industry has not traditionally done a good job of engaging students from these groups, and has also struggled, for a variety of reasons, including a lack of attention to the issue, to retain these workers once they get into the workforce. This attrition has given the industry a poor reputation for diversity, they said, among potential workers from these groups. One stakeholder noted that it took years of work before encountering another person from a similar background, a situation that made it more difficult to feel comfortable and engaged in the profession.

One AAM Industry Stakeholder's Perspective
"The first question I am asked at trade shows is how companies can find enough qualified workers from underrepresented groups. The second question I am asked is how companies can find enough qualified workers from any background."

Source: GAO Interviews with Selected Advanced Air Mobility Industry Stakeholders. | GAO-22-105020

Other stakeholders we spoke with expressed concern that many potential AAM workers are not aware of opportunities that exist in the industry. They said that students may not be aware of what jobs are available, what kinds of careers entry-level positions can lead to, and what educational opportunities exist to prepare them for those jobs. They cited several reasons for this: the fact that the AAM industry is not large and visible enough for students to see its potential; a perception that the aerospace industry in general is no longer an innovative place to work; as well as a perception that 4-year degrees necessarily lead to better paying jobs than careers in aviation maintenance and other support positions.

Some stakeholders we interviewed suggested that the AAM sector could present a new opportunity for the industry to reach traditionally

underrepresented groups. These stakeholders offered that since the AAM industry is in many ways starting from scratch in the minds of the public and because some early AAM companies have made a visible commitment to hiring a diverse workforce, the AAM sector may be able to shed the aerospace industry's poor reputation for hiring outside its traditional pool. Moreover, they said that an industrywide commitment to diversity would be important to avoid the workforce challenges experienced by traditional aerospace firms. These stakeholders emphasized a need to make students aware that many positions in the AAM industry offer well-paying, innovative jobs that employ cutting edge technologies. They said that while traditional aerospace may not appear as exciting for young people as it once did, excitement about drones sparked by the advent of the new UAS industry demonstrates that emerging aerospace fields such as AAM can, like the space race of the 1960s, spark increased interest in science and technology fields, captivate the public, and generate interest in new careers.

One AAM Industry Stakeholder's Perspective

"It is important for the aerospace industry to demonstrate to the public that it is an attractive and innovative place to work. People might not know about what opportunities are available in the AAM industry because it is so new. The AAM industry has great opportunities for people to get good jobs, but they won't help much if people don't know they exist."

Source: GAO Interviews with Selected Advanced Air Mobility Industry Stakeholders. | GAO-22-105020

FAA and NASA have a number of programs underway to improve the diversity of the aerospace workforce, including AAM. In response to the FAA Reauthorization Act of 2018, for example, FAA established the Women in Aviation Advisory Board to provide recommendations and strategies to FAA to encourage and support female students and aviators to pursue a career in aviation.[40] This board renewed its charter in October 2021 and among its duties is to develop a plan to encourage women's involvement in the aviation field. This plan will consider industry trends that affect women's participation in aviation careers, strategies for encouraging women to consider aviation careers, and ways to identify and promote success stories for women in aviation. In addition, NASA administers the Minority University Research and Education Project, which provides financial assistance via competitive awards to minority-serving institutions to enhance their ability to conduct aerospace research

[40]FAA Reauthorization Act of 2018, Pub. L. No. 115-254, § 612, 132 Stat. 3186, 3402.

and train workers from underrepresented and underserved communities.[41]

Limited Training Capacity

Some stakeholders also emphasized that training an AAM workforce may require more instructional capacity and equipment than currently exists for aerospace workers. Stakeholders expressed a concern over what they said is a likely shortage of these resources. Some said current aerospace training facilities may not be able to produce sufficient numbers of workers to handle demand from both the traditional aerospace sector and the emerging AAM industry. They said many aerospace training facilities, particularly those that train pilots, are already overstretched due to a lack of flight instructors, among other challenges.

Nevertheless, most stakeholders we spoke with said that they believe most AAM industry workers will train at these traditional aerospace training facilities, namely colleges, universities, trade schools, and the military. Many stakeholders stressed the important role they believe community colleges and trade schools will play in training the AAM workforce, particularly for maintenance technicians, but they noted that these institutions would need government support to structure their programs accordingly. In addition, some stakeholders stressed the importance of apprenticeships, cooperative education, and other experiential learning programs that place students with AAM companies. However, some other stakeholders said that AAM companies may not be able to wait for educational institutions to develop new training programs and may choose to develop training pathways of their own, especially for positions such as pilots and maintenance technicians that require a large degree of aircraft-specific knowledge.

One AAM Industry Stakeholder's Perspective
"With our current levels of funding we can only graduate about 15 [engineering] students per year, but there is such a need that there are about five available jobs for every student we graduate.

Source: GAO Interviews with Selected Advanced Air Mobility Industry Stakeholders. | GAO-22-105020

FAA and NASA officials described small programs that each agency administers to improve aerospace training capacity including by improving the skills of students entering training programs, boosting the ability of

[41]A minority-serving institution is historically black college or university, a Hispanic serving institution, a Tribal College or university, an Alaskan Native-serving institution or a Native Hawaiian-serving institution, a Predominantly Black Institution, an Asian American and Native American Pacific Islander-serving institution, or a Native American-serving nontribal institution. 10 U.S.C. § 1067q.

educational institutions to train workers in these fields, and increasing students' interest in aerospace careers. For example, FAA's Science, Technology, Engineering, and Mathematics (STEM) Aviation and Space Education (STEM AVSED) program helps recruit new workers into aviation fields by collaborating with public and private sector entities to promote aviation-related STEM skills and grow the pipeline of students seeking to work in aviation. This program offers programs for K-12 students such as the Real World Design Challenge that poses technical engineering challenges to high school students and the Smart Skies middle school math program that uses air traffic control challenges as a model.

NASA also has a number of programs for STEM engagement related to AAM. These include an AAM Academy classroom series for middle and high school students where NASA experts teach STEM concepts in a virtual environment. There is also the STEM Stars web chat program for high school students that introduces STEM careers and highlights how they relate to different NASA missions. Finally, NASA's Educator Professional Development Collaborative webinars help K-12 educators teach STEM fields and engage students in STEM topics.

Stakeholders Said AAM Will Require New Training Standards and Curriculums

Training pilots, maintenance technicians, and other AAM workers for an emerging industry presents a chicken and egg dilemma, according to stakeholders, because eVTOL aircraft and AAM services have yet to be developed and certified. Therefore, aviation training facilities do not have standards on which to base any curriculum. On the other hand, it can take years to develop such programs, and waiting for industry to finish developing aircraft before developing curriculums could leave facilities far behind in supplying the industry with workers. Stakeholders stated that training facilities may be hesitant to invest resources in developing AAM programs before they know what the successful technologies, operations, and demand for training will be. A few stakeholders said that schools may face additional challenges because AAM equipment, such as out of service aircraft commonly used for maintenance training, are not yet available for use in training. Some of these stakeholders suggested the AAM industry may resolve the shortage of equipment by making more extensive use of flight simulators and other virtual training devices such as virtual reality headsets for maintenance training.

Underscoring the potential lag in training curriculums is the fact that some of the FAA standards training providers typically use as a basis for aerospace training are out of date. For example, FAA requires schools that teach aviation maintenance technicians to follow a certain curriculum

that is specifically prescribed in regulations. In 2020, we reported that FAA's curriculum requirements for maintenance technician schools have remained unchanged for decades and do not emphasize commonly used modern aircraft technologies, such as avionics and composite materials.[42] Noting this problem, some stakeholders said that these standards may not be adequate, therefore, to cover the needs of AAM workers because they do not require schools to teach, for example, skills relevant to electric drive systems and advanced avionics.

Meanwhile, since 2015, FAA has been working on updating the curriculum requirements for maintenance technician schools through the rulemaking process. The agency has not yet finalized them and has missed two statutory deadlines to do so. These include the FAA Reauthorization Act of 2018, which directed FAA to issue a final rule to modernize training programs at AMT schools by April 2019, and the Consolidated Appropriations Act, 2021, which directed FAA to issue interim final regulations by March 2021.[43] FAA officials told us that the agency plans to release a final version of these requirements in the first half of 2022.[44] These officials maintained that the new standards would allow schools greater flexibility to teach new aircraft technologies by requiring that they meet certain broad standards rather than laying out specific curricula through regulations.

For pilot certification, FAA defines aircraft with characteristics of both airplanes and helicopters, such as eVTOLs, as a separate category of "powered-lift" aircraft and requires pilots of these aircraft to have a powered-lift category rating on their pilot's certificate. However, since no powered-lift aircraft have entered civilian service, according to FAA, the only pilots that hold a powered-lift category rating are those pilots who flew powered-lift aircraft in the military. As a result, FAA officials said there is not a well-defined civilian training pipeline for powered-lift pilots. According to FAA data, as of the beginning of 2021 fewer than 500 pilots held certificates with active powered-lift certificates out of about 460,000

[42]GAO-20-206

[43]Pub. L. No. 115-254, § 624(a), 132 Stat. 3186, 3404; Pub. L. No. 116-260, § 135(a), 134 Stat. 1182, 2356.

[44]According to DOT's regulatory agenda published in January 2022, the agency plans to publish the interim final rule in May 2022.

total active pilots.[45] To address issues related to assuring eVTOL pilots have sufficient skills in multiple flight modes, FAA's 2022 regulatory plan includes a rulemaking to incorporate powered-lift aircraft into current operating regulations for airplanes. The agency said this action would enable pilot certification for these types of aircraft. Officials said this rulemaking is intended to address some of the pilot certification and training issues for these types of aircraft and help ensure that FAA is able to certify appropriately qualified pilots when these aircraft enter service. FAA plans to issue a proposed rule on this topic in May 2022.

AAM Timelines Will Depend on How Industry and Government Address Unresolved Issues

Stakeholders identified three key factors they said would determine how fast the industry will develop.[46] First, they said the speed at which AAM manufacturers achieve eVTOL aircraft certification would have a significant impact on the start date of initial operations. While the industry is focused on certificating aircraft in the next one to 5 years, stakeholders expressed concern that, as discussed above, FAA does not have clear standards for how to certificate these aircraft, and the development of clear standards may extend beyond this time frame. In addition, stakeholders did not expect to see widespread AAM operations until infrastructure—such as vertiports, charging stations, and modified electrical grids—are developed. Last, stakeholders said that the industry's timeline depends on its ability to identify markets with sufficient demand for profitable AAM operations.

On the other hand, stakeholders had mixed views on what the initial AAM use-cases will be. For example, some believe that medical transportation services and point-to-point cargo delivery should be the initial use-case for eVTOL aircraft, because FAA has so far been more comfortable certificating cargo-carrying operations using new technologies such as UAS and the cargo business model has greater certainty and less sensitivity to unexpected operating costs. However, other stakeholders said that passenger-carrying operations such as urban air taxi and airport shuttles are viable early use-cases for eVTOL aircraft, and maintained

[45]This total excludes pilots holding only student, sport, or recreational pilot certificates. Of these pilots, nearly 400,000 held ratings only for airplanes, while about 30,000 held ratings for helicopters.

[46]Sixteen stakeholders identified factors that may affect the operational timeline of AAM, including the speed at which aircraft manufacturers achieve certification, how quickly industry and government can develop the necessary infrastructure, and the industry's ability to identify markets with sufficient demand for profitable AAM operations.

that operating costs will be low enough to allow pricing on those routes to be competitive with existing surface transportation operations.

Many of the stakeholders we spoke with said at least limited-scale AAM operations will begin in the next 5 years.[47] They said that initial operations would likely be limited in terms of the number of locations where AAM services are offered and the number of aircraft that are operating. For example, they would likely consist of small numbers of aircraft flying fewer than 10 routes in each of 2–5 metropolitan areas. Stakeholders stated that the first 5 years of operations will be slow and deliberate because aircraft manufacturers will be going through the FAA certification process, figuring out operational procedures, developing the capabilities of the aircraft, and proving the various operational and business models.

Beyond 5 years, some AAM stakeholders we spoke with projected that AAM operations will begin to grow at a faster rate and the industry would achieve more widespread operations by the tenth year.[48] Our stakeholders also suggested these operations will encompass passenger carrying operations in a significant number of metropolitan areas with, for example, operations taking place in 10–15 additional metropolitan areas and large-scale operations in the original cities. However, other stakeholders indicated that industry projections about the rate of AAM growth were optimistic, or they were uncertain about widespread AAM operations until further in the future. For instance, four stakeholders said that operations in 10 years would be limited in scale. They said that limited operations may be due to early AAM traffic being primarily among the wealthy, a situation that could undermine community acceptance, and that it remains to be seen whether there is enough of a commercial market for these operations to be viable. Beyond 10 years, however, additional stakeholders envisioned AAM becoming a major part of the U.S. transportation system provided that early operations can demonstrate clear benefits to the public.

Agency Comments

We provided a draft of this report for review to the National Aeronautics and Space Administration and the Departments of Defense and Transportation. The National Aeronautics and Space Administration and the Department of Transportation provided technical comments, which we

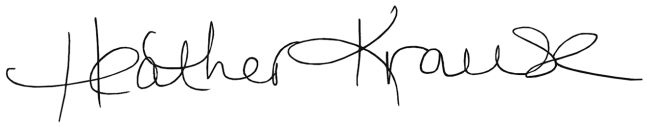
[47]Twelve stakeholders said that AAM operations will begin in the next five years, but that those operations will be limited in scale.

[48]Fourteen stakeholders said that AAM operations will grow quickly beyond five years and become more widespread by 10 years.

incorporated as appropriate. The Department of Defense had no comments on the draft report.

We are sending copies of this report to the appropriate congressional committees, the Secretary of Transportation, the Administrator of the National Aeronautics and Space Administration, the Secretary of the Air Force, and other interested parties. In addition, the report is available at no charge on the GAO website at https://www.gao.gov.

If you or your staff have any questions concerning this report, please contact me at (202) 512-2834 or krauseh@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made key contributions to this report are listed in appendix II.



Heather Krause
Director, Physical Infrastructure

Appendix I: Organizations GAO Interviewed

Table 2: Organizations Interviewed by GAO, by Category

Category	Organization
Advanced Air Mobility Companies: Aircraft manufacturers, aircraft operators, and bodies representing these companies	Aeronautical Repair Station Association Aerospace Industries Association Archer Aviation Beta Technologies Community Air Mobility Initiative General Aviation Manufacturers Association Helicopter Association International Joby Aviation National Air Transportation Association National Business Aircraft Association Vertical Flight Society Wisk Aero
Infrastructure Organizations: Airports, air traffic management organizations, electrical utilities, electrical engineering consultants	Airspace Link Black and Veatch Los Angeles International Airport Signature Flight Support Skyports
Non-federal entities and standards organizations: Non-federal entities such as state and local governments and standards organizations that establish rules and standards for AAM	American Society of Testing and Materials City of Los Angeles Kansas Department of Transportation National Association of State Aviation Officials National League of Cities Ohio Department of Transportation Washington State Department of Transportation
Professional Organizations: Organizations representing aerospace workers	Air Line Pilots Association Women and Drones Women in Aviation International
Travel Organizations: Tourism and business travel organizations	Global Business Travel Association US Travel Association
Worker Training Organizations: Community colleges, universities, trade schools, and training consultants	Aviation Technician Education Council CAE Inc. Embry Riddle Aeronautical University Georgia Institute of Technology Northland Community and Technical College Pennsylvania State University Utah Valley University

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Appendix II: GAO Contact and Staff Acknowledgments

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Staff Acknowledgments

In addition to the contact named above, Vashun Cole (Assistant Director), Ed Laughlin (Assistant Director), Alex Fedell (Analyst-in-Charge), Amy Abramowitz, Bennett Adamson, Seun Ajayi, Sue Bernstein, Christopher Jones, Matty Njie, Joshua Ormond, Kelly Rubin, and Alicia Wilson made key contributions to this report.

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