MITRE's Response to the DOT RFI on Advanced Air Mobility

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MITRE operates the Center for Advanced Aviation System Development, an FFRDC, on behalf of the Federal Aviation Administration (FAA). It also supports multiple other federal agencies that operate in the national airspace and regularly collaborates with private sector entities on aviation and broader transportation concerns. We have undertaken many projects and studies related to Advanced Air Mobility (AAM), helping to prepare our sponsors for the future. This response is based on the insights from those activities.

Overarching Recommendations

The RFI solicits public input about what should be addressed in a national AAM strategy, the barriers that exist to its implementation, and focus areas for the federal government. MITRE considers the most important aspects of a national AAM strategy to be (1) a clear vision, including a more mature and broader concept of operations with standard definitions; (2) coordination of government approval processes; and (3) a focus on safety.

A Clear Vision

To be successful, a national AAM strategy must serve a conceptual organizing function. It should first state the national vision for AAM operations in the United States followed by a collection of goals that enable the vision to be met. Each goal should be supported by a collection of subordinate objectives that include specific tasks or actions for the community to meet. These objectives and actions inform the Concept of Operations (CONOPS) and provide the Department of Transportation with the ability to measure and track whole-of-nation progress.

The national vision for AAM and its related CONOPS are critical to drive collaboration towards common goals and to identify required new standards. A national AAM strategy should promote standard terminology to avoid confusion and overcome inconsistent assumptions regarding new technologies and operational concepts. A national AAM strategy for should also expand the existing CONOPS for Urban Air Mobility (UAM)[1] to include regional and other non-urban use cases that are part of AAM.

This AAM CONOPS should include a set of most-critical operational scenarios that provides the foundation for determining requirements and enables the community to undertake a rigorous systems engineering process within and across operational domains.

Coordination of Approval Processes

A national AAM strategy should include coordination and streamlining of government approval processes that are critical to the implementation of AAM. Many elements of the National Airspace System (NAS) require federal, state, and local government approval.[2] Still other approvals are necessary to ensure the safety of air navigation, such as for obstacle construction. Over decades, the processes to seek, consider, and grant approval (including for certification) have co-evolved with technologies and practices.

AAM's diversity of aircraft and mission profiles, introduction of cooperative airspace management, reliance on new service suppliers and community-based rules, and the anticipated pace of growth will challenge today's approval systems. While AAM is an emerging system of systems (SoS), its components are to be approved separately. The need to recognize dependencies will be greater than it has been for the approval of incremental changes to mature systems. Moreover, an exception-based approach (using waivers, letters of agreement, or special authorizations) would overwhelm local systems and hinder repeatability and scalability. Approval processes must also recognize and encourage emerging best practices without setting precedents unsuited to later entrants.

A national AAM strategy should adequately prepare agencies, especially the FAA, for an influx of approval requests. A repeatable, scalable approval system would include three features:

- the use of playbooks whereby effective solutions to recurring problems are recognized and presented as guidance;
- the development and adoption of digital engineering tools to streamline approvals and support continuous review;
- the application of outcome-oriented approvals that enables change management, address integration issues, align schedules, and that ensures government-industry-community partnerships take a holistic view of their common goals.

Focus on Safety

In the U.S., AAM will become part of the world's safest airspace system. The implementation and integration of its novel and innovative concepts will be guided by its safety institutions and culture. Self-governance is a critical principle of safety management systems (SMS). The need for self-governance in AAM is especially significant given the imminent and rapid pace of change in an operating environment unaccustomed to dense traffic and the emergence of largely automated systems. Under existing and proposed Federal Aviation Regulations, many of the organizations involved in the production and operation of AAM aircraft will be required to implement SMS. The national strategy should encourage early development of SMS programs. It should also educate original equipment manufacturers (OEMs) and operators on best practices to ensure the effectiveness of SMS programs and to promote a positive safety culture and the benefits thereof.[3]

Safety Risk Management (SRM) is also a critical component of safety. The introduction of AAM into the NAS will add unprecedented complexity to SoS environment. Therefore, the national strategy should encourage the adoption of risk assessment approaches and toolsets offered by standards bodies, such as ASTM International, RTCA, and SAE International. The strategy should also encourage the international harmonization of such standards. In addition, a dedicated effort must be made to develop new advanced SRM tools for SoS complexity issues. The FAA should identify these SRM tools in its approval process guidance and clarify target levels of safety. Finally, the FAA should consider a hierarchical approach to prioritize safety investments, facilitate local decision-making, and improve risk monitoring.[4]

Responses to Specific Questions

1. *Most Likely Use Cases*

The value proposition for AAM is strongest where the cost of savings (e.g., time, emissions) exceeds the additional time investment (e.g., ground transport, onboarding) and inconvenience of use (e.g., ground transport, ride quality). This value proposition is most easily realized for users desiring to cross large, congested, geographically constrained cities where ground transportation may take hours; or for users with time-critical transport needs. The value proposition is expected to improve as increasing numbers of aircraft operate more regularly to and from an increasing number of airport and vertiport locations. In the near term, MITRE anticipates the following use cases will prevail.

Airport Shuttle Routes. These routes will consolidate demand to and from airport terminals and will take advantage of business travelers' willingness to pay the initially high trip cost. Routes and partnerships between AAM manufacturers and airlines operating from certain major airports have recently been publicly announced[5,6]. Analysis suggests that demand for these routes will be driven, at least in part, by operators' ability to integrate operations to airside vertiports inside the security perimeter of current airports. The anticipated time and cost benefits for AAM airport shuttle routes are greatest for trips 60–90 minutes (by automobile) from the destination. The initial low demand for AAM airport shuttles balances well with the anticipated small size of the AAM aircraft fleet and accompanying vertiport network.

Cargo Operations. Remotely piloted, AAM cargo operations will enable package movement and delivery on shorter timescales and with reduced costs. Such capabilities will increase supply to satisfy the growing e-commerce demand from the public.

AAM battery-electric propulsion systems will be limited by the range, payload, and all-weather capabilities of the aircraft. The ability to scale AAM will depend on several factors. Whether due to new propulsion technology or automated flight capabilities, AAM operations will be limited during inclement weather until airframes and sensors are deemed safe for all-weather operations. Furthermore, operations will be limited in some markets due to voice communication capacity constraints in already congested airspace. Large-scale AAM operations will also depend on improvements to controller procedures and accompanying technological capabilities that reduce human workload by automated (or assisted) routing and clearances.

2. *Safety Enhancements*

A national AAM strategy should encourage the use of automated flight control, navigation, communication, and data exchange to reduce or eliminate constraints related to human performance. Digital (non-voice) communications will reduce miscommunication and misinterpretation of clearances and instructions. Automated deconfliction, routing, and rerouting will resolve future conflicts before the need arises to perform evasive maneuvers or collision avoidance. Capabilities to automatically detect, alert the pilot or autopilot, and avoid collisions will offer improved performance over human perception and response during Visual Flight Rules (VFR) operations. Detect and avoid capabilities in Instrument Flight Rules (IFR) or Digital Flight Rules operations will maintain safety levels while increasing throughput and operational efficiency by reducing separation. Automated flight control and navigation increases the predictability and reliability of operations while reducing the most common pilot errors leading to loss of control or controlled flight into terrain. The full benefit of these automated capabilities will only be realized with the adoption of standard responses by automated systems during off-nominal situations to ensure common expectations among all operators. Without standard responses, each operator may respond differently to unexpected behavior from other aircraft. Such responses have the potential to ripple throughout the network and introduce delays (including ground holds). Such delays will frustrate operators and passengers for AAM and conventional aviation.

3. *Expected Customer Experience*

Customer experience with AAM will directly influence public acceptance and will drive market success. Ride quality may be an issue for small aircraft with low wing loading operating at low altitude in warm temperatures with wind gusts. As OEMs pursue speed to satisfy market demands, noise attenuation will be less effective and may become a greater nuisance to passengers (the market will likely demand speeds that cannot be delivered with the low noise signature typical of slower electrically propelled aircraft). While electric motors have demonstrated reduced noise from the propulsion system, questions remain regarding passenger tolerance for aerodynamic noise (propellers) and associated vibration. Passengers are likely to be anxious and lack trust during early phases of automation, remote piloting, and autonomy[7]. A national AAM strategy should anticipate some passenger dissatisfaction in its forecast for market demand during early phases of operation.

4. *Research, Development, and Testing Environment*

A national AAM strategy should establish virtual test sites. Virtual test sites should leverage high-fidelity modeling and simulation capabilities to perform preliminary verification and validation of automated control and autonomy approaches. Testing using virtual test sites will reduce over-reliance on low-fidelity and mid-fidelity environments that may not expose design and operations flaws.

A national AAM strategy should expand the availability of physical test sites. Current physical test sites are generally intended more for small and medium-sized unmanned aerial systems (UAS) and should be expanded to accommodate AAM. Operational airspace sandboxes should be established to conduct low-volume operations with multiple participating entities in a network.

A national AAM strategy should encourage the use of simulation environments for aircraft type certification credit and for pilot training credit. Aircraft flight testing programs are expensive and time-consuming. With the increase in use of digital flight controls, distributed propulsion, and automated navigation, there is an opportunity to make better use of hardware-in-the-loop simulations to establish baseline performance for large regions of the performance and operational envelope of aircraft. Physical, live flight tests should still be used to validate simulation data and for obscure conditions or edge cases.

A national AAM strategy should encourage research of fire retardants for non-combustion propulsion systems such as electric batteries.

5. *Statutory and Regulatory Scheme*

A national AAM strategy should extend the regulatory concept of "crew" beyond the current interpretation of "pilot in command". This revision will accommodate anticipated changes to human roles as automation becomes increasingly common in operations. Existing visual and instrument flight rules present a variety of legal, regulatory, operational, and procedural challenges to automated and autonomous flight. A national AAM strategy should encourage the development of a set of flight rules for automated and autonomous operations to complement VFR and IFR. As noted above, a national AAM strategy should also encourage the adoption of repeatable, scalable processes and procedures to approve automated and autonomous systems for use in the NAS.

6. *Role of State, Local, Tribal, and Territorial Governments*

See comments in (13) on role of local government for vertiport siting.

8. *Supply Chain*

A national AAM strategy should acknowledge that AAM airframe lifetimes may be significantly less than those for traditionally configured aircraft because technological advances will force obsolescence. This phenomenon will be further facilitated by vertical integration and close partnerships between manufacturers and operators such that AAM aircraft are removed from service without the burden of long-term (i.e., 30+ years) sustainment. This reality should inform expectations of long-term sustainment and access to replacement parts and materials.

Nevertheless, the AAM industry will be heavily dependent on the battery, electric motor, and semiconductor industries and their respective supply chains. Battery sourcing issues may put undue burden on regulators to approve electrically powered aircraft if sourced overseas without tight control of the manufacturing process. As automated capabilities become mainstream, these dependencies will deepen due to increased demand for computer processors capable of running machine learning, artificial intelligence, and other autonomy algorithms.

The electrification of all modes of transportation (e.g., aviation, automotive, rail, marine) is placing a strain on the supply of copper and rare earth metals. Electric motors, batteries, and aircraft wiring all require copper. A national AAM strategy should recognize the need to increase mining capacity for copper and rare earth metals.

A national AAM strategy should acknowledge the cybersecurity needs for the supply chain of hardware and software related to critical safety systems. Systems related to communication, navigation, and surveillance will need to be cyber resilient due to current and future threats of intrusion and manipulation. Cybersecurity protections start at the development and production of the parts making up the system. Standards and policy supporting cyber resilience in the supply chain will increase AAM safety and security.

10. *Workforce Development*

A national AAM strategy should encourage communities to educate and train the workforce to support AAM. This increasingly digitized world will require more data scientists and cyber experts. There will be an increased need for a workforce to process passengers and baggage and to ready vehicles and passengers for flight. The increased use of electric technology will also require training for vehicle maintainers. A national AAM strategy should leverage lessons learned from electrical systems on current aircraft (e.g., APUs) and lessons learned from electrification in the automobile industry. Furthermore, the AAM field is drawing from a shrinking pool of pilots. This stands counter to the phenomenon observed during the rise of UAS prominence where hobbyists were brought into the fold as pilots. AAM operational needs may further strain the pilot pool for general and commercial aviation.

Our response to Question 4 noted the importance of AAM flight simulators for research, development, and testing. The national strategy should also encourage the use of flight simulators to reduce the time and cost of training pilots in the AAM ecosystem. This will be important as remote piloting and supervision becomes more prominent and available to traditionally underrepresented groups in aviation. Commercial pilots today must log over a thousand hours of time as pilot in command; a greater reliance on simulators will reduce the cost and the risk of meeting such requirements.

11. *Global Leadership and International Practices*

A national AAM strategy should clearly define the phrase "durable global leader in AAM and safe automated technologies" to include an objective statement and one or more observable metrics. Goals should differentiate between ambitions for domestic firms to achieve and maintain global market share with the desire for U.S. regulatory leadership in aviation safety, which is far more collaborative in nature.

12. *National Security and Aviation Security Implications*

A national AAM strategy should address the need to seamlessly share information between civil and military organizations to satisfy national security and aviation security concerns. Security organizations desire assurances that rogue actors cannot commandeer or hijack AAM vehicles for malicious or nefarious purposes. This concern is amplified for remote or automated operations over urban areas where timelines and distances are very short between incident initiation and conclusion.

Because AAM technologies will find both civilian and military applications, considerations should begin now to monitor and protect domestic firms from intellectual property theft, as well as to screen foreign investments and joint ventures across the value and supply chains to appropriately consider military access to capability and capacity in the future.

Also, see comments on cybersecurity in *Section 8, Supply Chain*.

13. *Vertiport Development and Operations*

MITRE has analyzed route performance of certain AAM networks in complex airspace. The results indicate that vertiport siting and route design can aggravate existing airspace congestion; in the worst case, AAM operations become infeasible. Vertiport locations will primarily be determined by operators and local governments based on demand, infrastructure, and availability of real estate. However, the effect on airspace must not be neglected. Potential vertiports should be coordinated with the local Air Navigation Service Provider and the FAA to ensure the viability of coexistence between AAM and existing air traffic.

14. *Electromagnetic Spectrum*

AAM operations will be highly dependent on the availability of communication, navigation, and surveillance (CNS) services to ensure the safety and regularity of flight for all actors in the airspace. In turn, CNS services are highly dependent on the availability of spectrum resources with appropriate electromagnetic characteristics and bandwidth to support all airspace users. Legacy CNS services were not designed to support some aspects of the AAM operational profile (e.g., dense urban canyons and future autonomous operations) and there is limited availability of Aviation Services Licensed Spectrum to support the needs of these capabilities. A national AAM strategy should consider the use of licensed electromagnetic spectrum resources that are not dedicated solely for use by aviation (i.e., Aviation Services Licensed Spectrum) if those resources can maintain the safety and regularity of flight in the NAS.

Furthermore, emerging communications and sensing capabilities for AAM may operate very close to or at frequencies already in use by radars and other communications systems. As hundreds or even thousands of these mobile transmitters and receivers operate, they will potentially cause interference to systems currently in use, degrading performance. Radars and communications systems currently in use may interfere with proposed AAM systems, limiting their viable deployment. A national AAM strategy should consider these challenges and potential solutions, some of which are proposed below.

MITRE collaborates with FAA spectrum managers and CNS program managers to ensure that aviation spectrum needs are met to maintain safety and efficiency in the NAS. The introduction of AAM operations challenges the presuppositions of aviation spectrum and CNS service management:

- MITRE has assessed command and control communications for vehicle and traffic management for UAS with a focus on C-Band spectrum. Depending on assumptions regarding UAS and AAM demand growth, the FCC-designated C-Band spectrum may not be sufficient to meet the needs of either community.
- Global Navigation Satellite System (GNSS) navigation and timing services are increasingly susceptible to radio frequency interference that may result in navigation and timing service degradation. This issue is currently being addressed by a cross FAA-DOD-DHS-DOT team charted to conduct analysis and develop tools for detecting and coordinating incidents of spectrum interferers outside of natural causes.
- Surveillance services face challenges. Independent service coverage (e.g., primary radar) is limited at low altitudes and in urban areas. Dependent surveillance (e.g., transponders, ADS-B) requires access to limited spectrum by legacy and new-entrant operators.
- Robust new network services (i.e., the Internet Protocol Suite or IPS, an IP network overlay designed to ensure data integrity and performance monitoring) are being planned for introduction in the NAS. IPS, when used in conjunction with licensed spectrum, has the promise of expanding the options for novel solutions.
- Given the significant safety-of-life implications of CNS services for AAM operations, there is a pervasive need for resilience to intentional and inadvertent interference.

15. System Resilience

A national AAM strategy should promote predictive safety, predictive security, and predictive maintenance using non-deterministic systems and alternate means of compliance. Modern software development cycles are much shorter than conventional aviation development and continued airworthiness cycles. Cybersecurity efforts (such as MITRE ATLAS[8]) will require the ability to respond quickly to system vulnerabilities that will be exposed by greater connectivity of advanced aviation systems. Such a strategy will require a more flexible approach to safety determinations than current comprehensive, coverage-based approaches. The national AAM strategy should encourage graceful degradation of capabilities while allowing graceful extensibility to respond to emerging needs.

Also, see comments on cybersecurity resilience in *Section 8*, *Supply Chain*.

17. Alternative Means of Navigation Beyond GNSS

A national AAM strategy should encourage development and implementation of navigation and localization capabilities beyond a reliance on GNSS. In addition to dual-frequency, multi-constellation GNSS, global alternatives include: Low Earth Orbit assets; ground-based navigation systems and fixed references such as Enhanced Long-Range Navigation; and signals of opportunity such as broadcasts from radio towers. Local (i.e., onboard) alternatives include inertial reference units, or inertial measurement units, as well as sensors (e.g., LiDAR, other electro-optical solutions, and RADAR) that must be paired with 3-dimensional reference maps of terrain or urban features, such as buildings, towers, and bridges. When GNSS is not available, a combination of sensors integrated into the Flight Management System may provide sufficient services to compensate for the loss of GNSS navigational signal.

19. *Automation Standards*

A national AAM strategy should consider a variety of approaches to implement automation and autonomy. These approaches lie on the spectrum from classical, deterministic methods to non-deterministic neural networks and machine learning algorithms. Whereas comprehensive, coverage-based testing and validation are well-suited to deterministic design methods, non-deterministic methods will require more flexible approaches, such as those based on probabilities or statistical confidence. All approaches will require disciplined management of requirements. Standards based on probabilities explicitly acknowledge the uncertainty that exists in all deployed systems, whether deterministic or not.

20. *Other Areas of Interest*

a) System Complexity

AAM will be a SoS that will grow quickly as it introduces new, diverse, and rapidly changing and intertwined technologies and roles for machines and humans. The resulting complexity – characterized by nonlinearity, randomness, and collective dynamics – will challenge traditional approaches to ensuring safety which deconstruct systems to their component levels. The national AAM strategy should adopt principles of a Next Level of Safety including a systems level approach, proactive monitoring and analysis, data democratization, and smart policy.[9] In addition, research must be conducted to improve tools for the risk analysis of systems whose complexity precludes a deconstructive approach.

b) Air Traffic Management

MITRE analysis suggests that, due to capacity constraints related to voice communications, separation, and sequencing in busy airspace (inside and outside Class B), operations in certain desirable markets will be limited long before market demand is satisfied. Furthermore, ground and airborne delays for AAM flights with short block times will have cascading network effects that reduce the value (time savings) of AAM trips unless the origin and destination are very far apart. A national AAM strategy should address this potential issue by encouraging the adoption of automated flight management and control and should prepare for the delegation of some air traffic services to third-party service suppliers.

c) Coordination of Efforts

Among the many contributions of industry, government, and academic thought leaders envisioning the future of AAM are many concepts of operations and roadmaps[10,11,12,13,14,15,16,17,18,19]. These attempts to describe the future are critical to socialization of ideas as well as coordinated planning, investment, and systems engineering. The national strategy should seek a healthy balance of convergent and divergent ideation. On the one hand, the strategy should recognize the FAA's leadership in developing an authoritative CONOPS. The strategy should also designate a lead body to articulate and champion consensus priorities, to establish a collaborative process by which they are defined and updated, and to define and track government and industry commitments. The Advanced Aviation Advisory Committee, chartered in June 2022, could fill this role much as the NextGen Advisory Committee has. Because harmonization with emerging standards and international norms is critical, the strategy should encourage engagement with entities like RTCA, ASTM, and the ICAO AAM Study Group.

On the other hand, the strategy should encourage sharing and awareness of candidate concepts and solutions as research and field experiences blossom around the nation and the world. The national strategy should promote knowledge sharing efforts like NASA AAM Ecosystem Working Group workshops, AUVSI conferences, FAA AAM Summits, and TRB's Aviation Group committees (esp. New Users of Shared Airspace AV095) as forums worthy of broad awareness. The strategy should also address the intelligence gathering and dissemination needs of the multitude of national and local decision makers implementing and integrating AAM.

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