Enabling Supervised Flight – Procedures, Communications, Navigation, Surveillance and Supporting Infrastructure

An Advanced Air Mobility Roadmap

A report by GAMA Electric Propulsion and Innovation Committee (EPIC)

Version 1.0 September 2024

Contents

1. Introduction

This document provides a roadmap for the communications, navigation, surveillance infrastructure and associated procedures, rules, and policies needed to enable fuller realization of remotely piloted / supervised flight in the digital National Airspace System (NAS). [1] The discussion is focused on U.S. domestic airspace, but includes – where applicable – considerations for other jurisdictions.

This roadmap provides a basis for priorities by both industry and government on timelines of most importance to industry progress from Entry Into Service (EIS) to Mature State. Industry applauds government attention to the long-term national vision; however, industry also emphasizes the need for dialog and agreements between FAA and industry to guide early priorities.

1.1 Recommended Enablers

The enablers for this evolution of the NAS that will more fully integrate these new operational concepts seamlessly are presented in summary here. This document describes specific changes and technologies that would allow remotely supervised vertical take-off and landing (VTOL) and fixed wing AAM aircraft to grow and flourish.

The list is not presented as requirements, as AAM aircraft will enter into service using the existing NAS procedures. However, to realize the benefits of remotely piloted/supervised aircraft, to include cargo flights and low altitude cross-metropolitan or urban air taxis, this list represents a direction for the evolution of the NAS. These requests are not presented in chronological order as there are no obvious dependencies among them. Some of the enabling technologies are already in development through the existing methods in the NAS, such as work on remote taxi rules and procedures, and the development of Command and Control Communications Service Providers (C2CSPs) and Providers of Services to UAM (PSUs).

The list of enablers is described in summary here, grouped into areas of applicability:

Communications

1. FAA to continue coordinating with industry and developing a roadmap to authorized operation of PSUs and Associated Elements (AEs) including C2CSPs, for both sUAS and for larger aircraft.
2. Explore cost-saving approaches to implementing ground-based networks as part of “any-to-any” voice air traffic control (ATC) connections with the remote pilot, to provide backup voice connections and improve latencies, particularly for satellite-connected command and control (C2).

Navigation

3. Build and expand low altitude TK routes or AAM corridors with a pathway to performance-based access for digitally enabled (remotely supervised) aircraft.

---

[1] While definition of remote supervisor pilot licenses is also needed, that topic is not treated in any depth in this document. When using the term “remote supervisor” and “remote supervisor/pilot,” we are referring at present to a remote pilot.

4. Add curved approaches for vertiports with extensive surrounding obstructions. In support of this need, revise the Instrument Landing System (ILS) requirement, as ILS only works on an elongated straight-in approach.
5. Update 14 CFR 135.165 to allow for other robust precision navigational technologies.
6. Eliminate the requirement for the visual segment in an Instrument Flight Procedure (IFP) to accommodate all-sensor based approaches and departures, at IFP development and in regulation.[2]
7. The FAA and industry need to develop and implement separation rules for traffic traveling below 3000 ft above ground level (AGL), leading to a regulation.
8. Define Detect and Avoid (DAA) operation in low altitudes (takeoff and landing guidance) particularly at non-towered airfields.
9. Continue to collaborate with industry to provide backups and secondary navigation systems to mitigate risk of Global Positioning System (GPS) spoofing, jamming, and urban signal blocking.
10. Provide a path to a strategic deconfliction flight plan capability for low altitude procedurally separated flights.

Surveillance

11. Using EIS operational data, review and amend the needed operational regulations, such as 91.113, to augment "see and avoid," to encompass approved digital detection methods (i.e., DAA).[2]
12. Review and amend regulations, including 91.113, to augment “see and avoid,” to encompass approved digital detection methods (i.e., DAA).
13. Establish DAA standards for landing and taking-off at non-towered airports.[2]
14. Add tactical intent information to a collaborative airborne channel, known as V2V. FAA and industry should develop a strategy for the role for V2V in the NAS.
15. Complete technical development, develop standards, and enable use of ACAS-X_R for rotorcraft, powered-lift, and fixed-wing aircraft.
16. Share Primary and Secondary Radar between Industry and Government.
17. Work to implement Ground Taxi Solutions.

Procedures and rules

18. Letters of Agreement (LOAs) and waivers allowing remotely supervised flight and specific airspaces will need to mature and those that become widespread, transition into standard operational procedures and specifications.
19. Further flesh out the concept and define the Digital Flight Operations (DFO) ruleset to determine its potential role in enabling autonomous or remote flight operations, leading to Digital Flight Rule (DFR) development.

---

[2] These three changes (6, 11, and 13) together enable elimination of a large set of waivers and exemptions.

The General Aviation Manufacturers Association (GAMA) and its AAM members look forward to working through the enumerated changes requested above with the FAA, ICAO, EASA, airports, and the stakeholder community to achieve the full operational capability vision.

1.2 Organization of Document

This document addresses three epochs:

- Entry Into Service (EIS)
- Roadmap beyond EIS
- Additional policy and system needs to realize Mature State

The EIS section describes how operations can and will be operated by AAM aircraft in the existing NAS with no or minimal changes to the NAS.

The Roadmap Beyond EIS section presents considerations for the evolution of the NAS with specific focus on traffic and separation technologies (e.g., DAA) and the use of third-party communications service providers.

The Mature State section summarizes an industry view of the strategic thinking needed for stable growth of the industry as supply and demand of AAM services come into balance. In this state the dynamics and uncertainties for aircraft production, market uptake, operational densities, airspace capacities, infrastructure needs, financial performance, and regulatory requirements would become increasingly predictable, even settled into more stable trends. The continuing industry growth in this state implies strategic investment by both industry and government in addressing related regulatory, policy and infrastructure needs prompted by continuously advancing technologies.

1.3 Purpose and Scope

Inspired by the potential of new technologies that are advancing under AAM, GAMA manufacturers foresee a potential evolution of the NAS, to provide for denser operations, more varied aircraft types operating in unsegregated airspaces, and safer operations for all users of the NAS.

To thrive and grow into full operational capability, consensus is needed on the infrastructure, procedures, processes, and technologies. While AAM vehicles will initially enter into service in the NAS with existing infrastructure and procedures, beyond that, there is an opportunity to take advantage of the evolution in sensors, infrastructure, and the regulatory environment to enable remotely piloted or remotely supervised operations of large aircraft in controlled airspace. The future NAS will be a performance-based environment, where pilot on board and remotely piloted aircraft are not segregated, but fly side by side in all airspaces.

This middle epoch of AAM technology and NAS evolution includes operations in all weather and enables digital flight operations. Digital flight operations, which allow for Visual Flight Rules (VFR) and Instrument Flight Rules (IFR) flights, regardless of pilot location, provide a practical approach to NAS evolution. This paper is intended to supply a single industry voice in identifying procedural, infrastructure, and technological changes to the NAS. Because the FAA only sees one aircraft certification at a time, it may be difficult for the FAA to define the roadmap.

This paper follows the GAMA AAM Entry Into Service Typical Capabilities List (TCL) white paper of 2023 with a description of the middle epoch. This white paper identifies near term changes to infrastructure and the regulatory environment. GAMA intends to use this consensus paper to discuss NAS evolution with FAA, its Innovate 2028 project teams, NASA, FCC, AIA, other industry organizations, including RTCA and other standards development bodies.

Describing this middle epoch is complex, as each AAM manufacturer plans a unique path from entry into service into expanding operations. However, this document outlines specific modernization initiatives that will benefit the entire AAM segment, and complementary to existing NAS users' modernization priorities. Potential concepts of operation will vary and may include:

- Some begin with a pilot onboard; others only provide a pilot onboard during the certification proving flights and plan commercial service with a remote pilot supervisor.
- Some plan to fly VFR and grow into VFR plus IFR operations.
- Some rely on IFR operations from the start.

Evolution in key regulations and policies is needed to align certification equipment[3] with operational permissions. Adaptation of airspace regulations should encompass detect and avoid with remote pilotage, permit sensor and digitally enabled[4] cooperative based flight without a pilot onboard, and provide operation in areas where traditional communication, navigation, surveillance (CNS) signals are blocked without a pilot onboard.

Enabling third-party will require industry, standards organizations, and government collaboration. Examples of third-party services include:

- commercial Communications Service Providers for remote pilotage,
- flight planning and strategic deconfliction,
- conformance monitoring and tactical rerouting/deconfliction,
- aircraft to aircraft communications for coordination, and
- ground-based surveillance enhancements.

Finally, some areas where solutions are going to take longer but are clearly needed include vertiport operational considerations, remotely piloted operational rules for low altitude Class E and G airspace, precision landing technologies without a long straight approach path, and ground taxi solutions. While this is not the end of the list, these are the enablers for which there is a clear case for implementation.

1.3.1 Purpose

This paper focuses on the middle epoch, which are the next set of years after EIS, and the CNS infrastructure and policies that are needed to move beyond initial operations. This roadmap discusses what has to happen after EIS to achieve fuller operational capability, and why. After the introduction, this paper lays the foundation of how AAM aircraft plan to enter into service with existing avionics, infrastructure, and regulation ("Entry Into Service" Section). This section is followed by the Roadmap,

[3] "Certification equipment" means the aircraft and all equipment onboard at the time of certification.
[4] Digitally processed information and sensor returns are provided to a remote pilot, enabling operator-responsible separation even in IMC conditions.

which describes avionics, infrastructure, and regulatory changes that enable fuller realization of AAM evolution.

1.3.2 Scope

This roadmap is concerned with type-certificated, large AAM aircraft that primarily operate in airspace above 400 ft AGL, using the GAMA definition of AAM:

> *"Civil Advanced Air Mobility (AAM) is a collection of new transformational technologies applied to the air transportation of people and cargo. AAM aircraft encompass increasingly automated type-certificated aircraft intended to operate in the same environments as existing rotorcraft and airplanes, utilizing air traffic services in the airspace above 400' AGL. AAM operations will be integrated into the national airspace system and include pilot-on-board, remotely piloted, or autonomous aircraft."*

The use of air traffic services in low altitudes, below traditional IFR altitudes, will be opportunistic; not all airspaces will support traditional CNS services (such as ATC voice, radar, and VOR/DME) due to signal blockage.

The development of smaller uncrewed aircraft systems (sUAS) operations (e.g., up to and including 1,320 pounds) is expected to occur in parallel to work on AAM integration in the NAS. In the near term, there are and will be small UAS performing cargo and surveillance missions, operating entirely below 400 ft AGL. These small UAS operations are expected to be defined by the FAA in the expected August 2024 Notice of Proposed Rulemaking (NPRM) for Beyond Visual Line of Sight (BVLOS).

2. Entry Into Service

The GAMA report, "Advanced Air Mobility Aircraft Entry into Service (EIS) Communication, Navigation, and Surveillance (CNS) Typical Capabilities List (TCL),"[5] surveyed AAM manufacturers' plans to commence revenue service largely with avionics already in use in the NAS and based on published standards and existing certification guidance.

Manufacturers will have novel propulsion, energy, airframe, surveillance, DAA and other systems as authorized in their Certification.

Operation at EIS will use existing NAS rules, with Letters of Agreement (LOA) and Memorandums of Understanding (MOU) to define special procedures and airspace operations. This is similar to the situation today, where LOAs, MOUs, and waivers are used by ATC to recognize and define specialized procedures for a given facility or fleet.

In addition, some remotely piloted EIS operations will require a Certificate of Authorization/Waiver (COA) where existing regulations do not fit the operations enabled through their certification.

2.1 Entry Into Service – Concept of Operations

While describing the various concepts of operation (CONOPS) that AAM manufacturers and operators will use at EIS[6] can be challenging, there will be consistent progressions as operations scale. For example, certain operators may initially have a pilot on board and operate under VFR, but over time transition into remotely piloted IFR operations. While this progress might not be uniform, this document seeks to identify commonalities across various CONOPS.

Example EIS CONOPS progressions envisioned by different manufacturers include:

- Begin operations using day-VFR; progress to VFR day and night operations, then to IFR operations;
- Begin operations under IFR with a remote pilot, with progression to more operational flexibility to enable procedures found under visual rules;
- Begin operations with a pilot on board then progress to automated flight with remote pilot supervision;
- Begin operations with no pilot onboard and relying entirely on remote pilot supervision – including M:N multi-vehicle supervision.[7]

---

[5] Advanced Air Mobility Aircraft Entry into Service (EIS) Communication, Navigation, and Surveillance (CNS) Typical Capabilities List (TCL), GAMA Electric Propulsion and Innovation Committee (EPIC), September 2023. https://gama.aero/wp-content/uploads/EPIC-Resource-Paper-Advanced-Air-Mobility-EIS-CNS-TCL_V1_01_09_2023.pdf

[6] Entry Into Service for most occurs before 2028.

[7] M and N represent numbers where M is the number of pilots in control of N number of aircraft. See "Unmanned Aircraft Systems Beyond Visual Line of Sight Aviation Rulemaking Committee," FAA, March 10, 2022.

2.1.1 Role of Autonomy in Remotely Piloted Operations

To understand the role of autonomy in remotely piloted operations, it is important to align on common definitions.

"Autonomous with human oversight," or "remotely piloted/supervised aircraft" have fully automated flight capabilities with communication and navigation oversight by the remote pilot/supervisor.

Primary and secondary flight control surfaces (e.g., ailerons, elevator, rudder and throttle) are fully automated for attitude and flight path control. This is consistent with the FAA definition of "human over the loop" piloting, with the International Civil Aviation Organization's (ICAO) "Remotely piloted aircraft system (RPAS)," and with ASTM International's "Automatic System."[8]

In this type of operation, the aircraft has the authority to automatically execute DAA resolution advisories (RAs) and RTCs (return to course). The aircraft follows a deterministic flight path, and has the ability to detect and respond deterministically to a finite set of rare events, including windshear, propulsion failure, or primary electrical system failure. The automation senses deviations in nominal operating parameters such as speed, attitude, and loading, for the given mission and flight phase, and responds according to a predetermined safety hazard analysis, which is encapsulated in the certification process. However, this is not a completely autonomous operation, as the remote pilot/supervisor interacts with ATC to modify the flight plan and maintain voice communication.

While "remotely piloted" has traditionally implied a person on the ground with near-direct control of primary control surfaces (aka, 'stick and rudder'), this is not the case for commercial AAM aircraft being certified today. These aircraft must have fully automated flight controls (i.e., the 'aviate' function) and the ability to safely complete a flight after the take-off command is received (i.e., the 'navigate' function) with the Remote Pilot in Command (RPIC) required to interface with ATC, respond to contingencies, and

---

[8] ASTM Advisory Committee (AC)377 Technical Report 1 (TR1), "Autonomy Design and Operations in Aviation: Terminology and Requirements Framework" (2020) provides these definitions:

> 3.4 AUTOMATED FLIGHT - A flight that follows predefined instructions and usually flies a predefined path (and potentially predefined contingencies) without intervention. A human may monitor and issue override instructions.
> 3.5 AUTOMATIC - The execution of a predefined process without intervention.
> 3.6 AUTOMATED SYSTEM OR AUTOMATIC SYSTEM - Hardware and software that automate a predefined process without the need for human intervention, an individual may monitor and override.
> 3.7 AUTOMATION - A holistic term used to refer in generalities to both automated and autonomous systems.
> 3.8 AUTONOMOUS - An entity that can, and has the authority to, independently determine a new course of action in the absence of a predefined plan to accomplish goals based on its knowledge and understanding of its operational environment and situation. Having the ability and authority to make decisions independently and self-sufficiently.
> 3.9 AUTONOMOUS FLIGHT - A flight that does not require human decision making and instead relies on automation that can independently determine a new course of action in the absence of a predefined plan to execute management or operational control of a flight.
> 3.10 AUTONOMOUS SYSTEM - Hardware, software, or a combination of the two that enables a system to make decisions independently and self-sufficiently. Autonomous systems are self-directed toward a goal governed by rules and strategies that direct their behavior.
> 3.11 AUTONOMY - The quality of being autonomous (i.e., without the need to be controlled by outside entities; self-determination).

integrate with other air traffic. A remote supervisor is a remote pilot who provides oversight over communications and navigation of a fully autonomous aircraft. Some manufacturers (original equipment manufacturers, or OEMs) are pursuing M:N operation at EIS. It remains to be seen whether M:N will be enabled for all airspaces at EIS by the FAA, or whether M:N will follow after the EIS point.

Remotely supervised aircraft are designed to operate safely without supervision, because of the possibility of loss of the supervisory command and control (C2) Link. While lost C2 link is not an expected occurrence, in aviation, safe flight follows when the operator has prepared operational procedures for continued safety following loss of key components. Guidance material developed by RTCA (DO-400) contains procedures to handle lost C2 link situations that align with the concept being codified at ICAO. In general, if airborne, the flight will continue on its last ATC clearance, relying on onboard flight, navigation, and flight management, and DAA systems. The aircraft will squawk a transponder code assigned for lost C2 link (7400), so that ATC and surrounding cooperative aircraft are made aware that the aircraft is currently executing a lost link procedure. Resolution of the lost C2 Link state depends on several variables, such as class of airspace, phase of flight and pilot-controller communications. In some cases, the most appropriate solution will be for the aircraft to continue to its destination to land; in others, the aircraft may follow a previously defined route to an alternate landing destination. The pilot will be able to notify the destination airport/vertiport of the lost C2 Link, and invoke procedures – generally created under an operating MOA or similar – to accommodate the incoming aircraft and enable safe landing.

2.1.2 Certified Aircraft

This document is primarily concerned with type certificated aircraft, including airplanes, rotorcraft and powered lift aircraft. The document includes powered lift and traditional aircraft with autonomy.

An aircraft with a type certificate (i.e., a Standard Category Certificate of Airworthiness) is able to operate commercially everywhere that it can be shown to meet its performance and operational requirements.[9] The same is considered true for type certificated AAM aircraft. The FAA's and other aviation states of design certification process is robust enough to ensure that operations through all classes of airspace, over any area, and through any meteorological conditions, is properly considered and accounted for. For AAM aircraft going through this process, there is no reason for the regulator to restrict operations beyond those chosen by the designer to reduce design requirements (e.g., Flight Into Known Icing).

The vast majority of AAM aircraft will be type certificated. In 2023 FAA proposed a reform of the special airworthiness certification process[10] (Modernization of Special Airworthiness Certification, or MOSAIC), which includes the framework for light sport aircraft and the authority of pilots who exercise sport pilot privileges.

[9] Type certification is the approval of the aircraft's design and all its essential components. Production certification is the approval to manufacture duplicate aircraft under the type design. A standard airworthiness certification means the aircraft is built to a type certificate, has been properly maintained, and is approved for normal, utility, and commercial operations. Special airworthiness is granted for personal, non-commercial aircraft use.

[10] 88 FR 47650, Modernization of Special Airworthiness Certification, Docket No.: FAA-2023-1377; Notice No. 23-10.

AAM aircraft and MOSAIC aircraft overlap, but are not wholly the same. Some AAM aircraft may be light sport aircraft under the proposed MOSAIC rule and will have special [limited] airworthiness that does not permit carrying paying passengers (i.e., MOSAIC is limited to non-commercial operations). This document recognizes these proposed light sport aircraft as potentially AAM, but this document focuses on enabling the integration of standard Type Certificated aircraft with no pilot onboard into the NAS.

2.2 Key EIS Procedures and Capabilities

This section describes some of the key novel procedures and capabilities used in near-term supervised and remotely piloted flight.

2.3 EIS – Communications, Navigation and Surveillance

Airborne equipage to support interaction with ATC is presented in this section to help inform CNS requirements for entry-into-service operations in the U.S. NAS. In addition, the airborne equipage described in this paper is also applicable outside the U.S., because manufacturers do not plan to have aircraft or avionics configurations tailored to specific markets, unless required by that jurisdiction.

The material presented in section 2.3.1, 2.3.2, and 2.3.3 is based on feedback gathered in a 2023 survey of aircraft OEMs to inform airborne equipage expectations at EIS for piloted operations. This section has also been augmented with additional information about planned airborne equipage for UAS at entry-into-service.

2.3.1 EIS – Communications

All aircraft OEMs indicated plans to use standard VHF voice communication for interaction with ATC.

Some OEMs also indicated plans to enable digital data link communications for specific functions such as Digital Automatic Terminal Information Service (D-ATIS), Universal Access Transceiver (UAT), and XM, for example, for traffic and weather awareness.

Supervised autonomous aircraft are planning to use C2 Link through satellite communications (SATCOM), and Radio Line of Sight (RLOS) datalinks (5030-5091 MHz and licensed UHF band). These are provided through C2CSPs.

2.3.1.1 EIS – Available C2CSPs

The concept of a C2CSP has been developing for years. Existing satellite service providers, such as Inmarsat and Iridium, provide satellite communication services to aircraft in oceanic airspace, and now provide command-and-control capabilities to large uncrewed aircraft.

UAS use Line-of-Sight (LOS) radio frequency (RF) links to communicate flight commands from a pilot who is within line of sight of the aircraft (e.g., existing part 107 operations)

When supervised/remotely piloted aircraft conduct BVLOS operation, typically there is an RF link from the aircraft to a ground station or to a satellite and then to a ground station, with a direct or networked connection from the ground station to the pilot. Maintaining a link to a pilot who can intervene if needed is a failsafe as hours of experience accumulate, to expose and prepare for low frequency of occurrence events.

The C2 link on remotely supervised AAM aircraft carries:

- Command, control and configuration messages between pilot and aircraft
- DAA messages
- ATC voice messages, relayed through the aircraft
- Flight safety and telemetry messages
- other messages, in order of priority.[11]

If an aircraft has onboard DAA airborne equipment, DAA surveillance information is provided over the C2 link to the remote pilot/supervisor. If the DAA processor is onboard the aircraft, ground-based surveillance systems' (GBSS) track information is provided to airborne DAA computers over the C2 link. The C2 link is a critical enabler of remote pilot/supervisors.

In addition to satellite, commercial C2CSPs have built terrestrial C2 link systems for remotely piloted aircraft and will offer commercial C2 service in 2024[12]. The availability, latency, integrity, and continuity requirements of these links were determined by FAA and industry safety and performance analyses, and were published in RTCA DO-377. Operators will likely have redundant terrestrial and satellite C2 capability onboard aircraft to satisfy very high reliability and availability requirements.

For remotely piloted operations, current procedures state the ATC voice party line must be preserved, by routing the received ATC channel transmissions through the aircraft via the C2 link to the pilot on the ground. Return responses from the pilot go by C2 link up to the aircraft and then are transmitted from the aircrafts' VHF radio over the air.[13] In the case of satcom, the voice and data over the C2 link are transmitted from the aircraft to the satellite, from the satellite to a ground station and to the pilot. Return responses from the pilot go through the satellite, are transmitted from the satellite to the aircraft, and then are transmitted from the aircrafts' VHF radio over the air. Because of the distance of transmission, satellite links may not be able to meet air traffic control voice latency requirements. If the terrestrial link is lost and the satellite link is primary, there will be procedural agreements to address these off-nominal cases. Terrestrial networks meet the stringent ATC voice latency[14] requirements.

Examples of the existing systems which by themselves or in combination with other systems may enable safety critical C2 communications include:

- Dedicated UHF C2, such as AURA Network System's national network;

---

[11] ICAO, "Annex 10 Aeronautical Telecommunications - Volume VI - Communication Systems and Procedures Relating to Remotely Piloted Aircraft Systems C2 Link," 1st Edition, July 2021. Prioritization of messages cited and invoked in RTCA DO-377.
https://store.icao.int/en/annex-10-aeronautical-telecommunications-volume-vi-communication-systems-and-procedures-relating-to-remotely-piloted-aircraft-systems-c2-link

[12] See for example https://uavionix.com/products/skyline/; https://auranetworksystems.com/network

[13] The relay of voice ATC through the aircraft is a requirement of the voice radio license granted to the pilot by the FCC. The FCC requested comments on this rule in FCC-22-101A1, released to the Federal Register January 4, 2023.

[14] Telemetry and telecommands generally have latencies of 1 second. While some less-urgent message latencies are longer, among the shortest is the average requirement for Air Traffic Control voice communication, at 250 milliseconds (ms). This was established by DOT/FAA in 2014 on the basis of safety-impairing levels of voice step-ons.

- C-band line of sight systems using 5030-5091 MHz band allocated by WRC 2012 and by ITU-R worldwide for UAS safety of flight C2, to be allocated by FCC, and which is expected provided by uAvionix;
- L-band SATCOM systems such as INMARSAT and Iridium.

These systems are or will be licensed by the FCC for exclusive aviation use. C-band is currently in experimental use awaiting FCC rule for permanent licensing.

Cellular band (5G) communications are being used by small uncrewed aircraft now for C2, particularly in terminal environments and over short distances (up to approximately 10 miles), and in ground operations. This cellular capability can be extended in these environments for non-safety-critical communications for AAM and other aircraft as a backup to the primary C2 connection.[15] The requirements for safety-of-flight C2 drive expensive requirements for network connections, which squeeze profit margins in cellular spectrum, and higher rate-of-return is easily found providing cellular service. While cellular air-ground C2 is possible, it is less likely during the middle epoch being described.

2.3.1.2 EIS–- IPS and Cybersecurity

The abovementioned C2 links systems are Internet Protocol Suite (IPS) compatible, and will be compatible with future Aeronautical Telecommunication Network (ATN) systems.

C2 systems are cybersecured with both physical security and encryption. The airborne link is immunized from spoofing and "man in the middle" attacks through establishment of private session links.[16] The cybersecurity of airborne radio is addressed in the aircraft certification process. Security of the ground C2 components will be overseen by the FAA, as with other ground aviation elements. FAA is developing frameworks to evaluate related components called "Associated Elements" (AE.)

2.3.1.3 EIS–- Ground Networks

As an alternative to routing VHF comms through the aircraft, third-party providers are planning to install ground VHF listening stations near FAA VHF transmitters and relay ATC audio through a ground network to the pilot. There is no prohibition on listening to VHF comms with this relay. However, the ability to transmit an answer from the ground is restricted. At present, VHF voice communications from the pilot of an uncrewed aircraft must be transmitted from the aircraft.

Transmission through these ground networks would eliminate VHF coverage gaps and offer a viable communication means leveraging well understood technologies and infrastructure.

DoD has recently begun limited transmitting over ground networks directly to ATC. Party-line sharing with other airspace users is accomplished by VHF retransmit at the FAA's antennas.

---

[15] HyperConnected ATM (https://www.sesarju.eu/sesar-solutions/hyper-connected-atm and https://www.easa.europa.eu/en/downloads/137252/en#:~:text=To%20be%20specifically%20mentioned%20are,the%20new%20terrestrial%20link%20LDACS

[16] Appendix L of DO-377A describes establishment of private sessions between the aircraft and the control station (CS) in both the User Plane and Control Plane, to ensure link security and prevent "man-in-the-middle" attacks. In addition, there are security sessions between the air vehicle and the C2CSP, and between the C2CSP and the control station, to provide an in-depth security solution.

2.3.2 EIS – Navigation

The primary navigation capability in terms of avionics on board piloted and UAS aircraft will be based on wide-area augmentation system (WAAS)-enabled, IFR-approved global positioning system (GPS) to support terminal and enroute procedures. Some manufacturers may also pursue Dual-Frequency and Multi-Constellation (DFMC) capabilities to support robust navigation and position capabilities.

Landing navigation aids include VOR-enabled navigation and VOR/DME-based Area Navigation (RNAV) capabilities as well as some DME/DME based RNAV. Most OEMs also plan for a standard 200 channel instrument landing system (ILS) / VOR with localizer and glideslope for LPV (localizer performance with vertical guidance) approaches.

14 CFR 135.165 requires onboard equipage of two independent navigation sources under IFR, which is met with above mentioned capabilities, and the capability of executing an instrument approach.

For many AAM manufacturers, GPS is a ready primary navigation source available anywhere along a route in the US. The use of an inertial reference system is regarded as sufficient to increase of reliability and availability for GPS to satisfy some operator use cases.[17] GPS-defined approaches are available at 1,239 airports, including all the "core" 30,[18] though often a manufacturer will equip its aircraft for a variety of approaches (VOR/DME/ILS) in order to provide both for safety analyses and an "operate-anywhere" future expansion. For instance, common navigation radios often include VOR/DME/ILS/GPS in a single in a single box or system.

Powered lift aircraft will use both existing heliports and airports. Instrument approach and departure procedures, including point in space approaches, need to be added to terminal instrument procedures (TERPs) for powered lift aircraft. The FAA recognized this in 2023 by proposing use of "Copter Procedures" for powered lift aircraft[19] entry into the IFR environment.

2.3.2.1 EIS – Letters of Agreement to Enable Specific Operations and Procedures

LOAs typically define responsibility for a given airspace or aircraft among available air traffic control persons/facilities/organizations. As noted in FAA Order, "LOA should be negotiated if the air traffic

[17] 14 CFR 135.165 (b): Use of a single independent navigation system for IFR operations. The aircraft may be equipped with a single independent navigation system suitable for navigating the aircraft along the route to be flown within the degree of accuracy required for ATC if: (1) It can be shown that the aircraft is equipped with at least one other independent navigation system suitable, in the event of loss of the navigation capability of the single independent navigation system permitted by this paragraph at any point along the route, for proceeding safely to a suitable airport and completing an instrument approach; and (2) The aircraft has sufficient fuel so that the flight may proceed safely to a suitable airport by use of the remaining navigation system, and complete an instrument approach and land.

[18] https://www.faa.gov/about/officeorg/headquartersoffices/ato/navigation-programs/masterrnavs-06152023-gpswaas-approaches

[19] 88 FR 38954 "…certain powered-lift type-certificate applicants may want their aircraft to have the capability to use Copter Procedures under Part 97, which would require the aircraft to have the specific equipage and stability capabilities equivalent to either Appendix B to Part 27 or 29 as part of the type certificate approval."

manager deems it necessary to clarify responsibilities of other persons/facilities/organizations when specific operational/procedural needs require their cooperation and concurrence."[20]

An example is delegation of responsibility over a specific airspace volume for a long period of time (e.g., years). Thus, a service carve-out under a Class B airspace may be assigned to approach control, or a smaller airport; or may be segregated for special operations. Thus, for some operators the use of LOAs are key enablers at the beginning of service.

AAM aircraft operations can take advantage of procedural separation through the development of LOAs with operational and procedural instructions with ATC. Examples include 14 CFR Part 91.159 (VFR Cruising altitudes, Special procedures under a LOA, reference Order 7210.3DD Section 3 4-3-1), such as Las Vegas LOA for Air Tour Helicopter operation, and Ultralight corridors into and out of controlled airspace.[21]

FAA has begun work to adapt IMC procedures to vertiports. GAMA looks forward to supporting the FAA's cross-line-of-business' Advanced Vertical Lift Team in these efforts.

2.3.3 EIS – Surveillance and Separation

In maintaining separation, pilots and controllers are assisted by several systems that detect aircraft and provide location information. Where controllers cannot provide positive confirmation of aircraft separation due to lack of radar and sensor coverage, procedural methods can be employed.

2.3.3.1 EIS – Automatic Dependent Surveillance Broadcast (ADS-B)

ADS-B is an airspace-based regulation where most civil aircraft in designated airspace are required to be equipped. While ADS-B airspace is limited across the United States below 10,000 feet, all large airports and many smaller airports are within ADS-B airspace volumes.

In the survey that informed GAMA's AAM EIS CNS TCL white paper, 100% of respondents indicated ADS-B Out equipage planned for aircraft in development by AAM OEMs. The survey covered primarily manufacturers of piloted aircraft but also some that are developing remotely piloted aircraft and derivatives of existing aircraft.

The FAA today provides guidance for use of ADS-B by UAS:

---

[20] FAA Order 7210.3, 4-3-1 (Letters Of Agreement.)

[21] A Certificate of Waiver or Authorization (COA) can be thought of as an authorization to use a regulation in a new way. It takes advantage of exemptions already written into regulations. For example, Part 91 many ATC/airspace-related regulations say, "unless otherwise authorized by ATC." A COA is the other authorization, such as operating in a given airspace without a transponder.
The FAA issues a COA that permits persons, public agencies, organizations, and commercial entities to operate a particular aircraft or equipment, or lack of equipment, for a particular purpose, in a particular area of the NAS as an exception to the FAA Regulations.
https://www.faa.gov/air_traffic/publications/atpubs/foa_html/chap4_section_3.html\
A LOA is a procedure, such as an altitude or angle of entry that will be used commonly by a given person, organization, in a given airspace.
https://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/systemops/aaim/organizations/uas/coa

- Large UAS aircraft that are remotely supervised or have no pilot onboard are expected to be equipped with ADS-B since they will be on a flight plan and communicating with ATC.
- Small UAS (Part 107 operations), for example, operating below 400 ft AGL are prohibited from using ADS-B,[22] for fear that the high numbers of small UAS would congest the available RF spectrum and saturate controllers.

Companies developing large UAS plans to equip the aircraft with ADS-B enabled Mode S transponders to ensure compliance with existing rules and FAA policy.

2.3.3.2 EIS – Procedural Separation

Procedural separation or control is a method of providing ATC services without the use of radar, or other ground or aircraft installed identification and position technologies. Rather it relies on time and navigation-based separation.

For example, aircraft traversing areas of Alaska that lack radar coverage are monitored with an ATC check-in at the point of exiting radar coverage, and with a check-in at the point of re-entering radar coverage.

Procedural separation is proposed as a method of permitting RPAS to traverse low altitude airspace that lacks radar coverage, at the time of entry into service. Future expansion of service is expected to build on this approach. Procedural separation takes advantage of longitudinal, lateral, and vertical separation as outlined in FAA Order JO 7110.65W.

2.4 EIS – Airborne Collision Avoidance System (ACAS)-Compliant Detect and Avoid (DAA) Systems

Another enabler of remotely piloted/supervised operations[23] are Airborne Collision Avoidance System (ACAS)-compliant DA) systems.

Traffic collision avoidance system (TCAS) I is mandated for use in the U.S. for turbine powered, passenger-carrying aircraft having more than 10 and less than 31 seats. TCAS I is also installed on a number of general aviation fixed wing aircraft and helicopters. TCAS II is mandated by the U.S. for commercial aircraft, including regional airline aircraft with more than 30 seats or a maximum takeoff weight greater than 33,000 pounds. Although not mandated for general aviation use, many turbine-powered general aviation aircraft and some helicopters are also equipped with TCAS II.

TCAS in the international arena is known as ACAS. Recent work to further develop ACAS has focused on better encompassing the maneuvering capabilities of powered lift aircraft and rotorcraft and well-clear distances for UAS.

[22] 14 CFR 89-109. https://www.govinfo.gov/content/pkg/FR-2021-01-15/pdf/2020-28948.pdf. Docket No.: FAA-2019-1100; Amdt. Nos. 1-75, 11-63, 47-31, 48-3, 89-1, 91-361, and 107-7.

[23] 50% of GAMA EIS CNS TCL OEM respondents indicated plans to leverage TCAS/ACAS equipage. Many of these respondents are focused on autonomous remotely supervised/piloted operations.

By supplementing legacy onboard pilot see-and-avoid capabilities, and potentially providing an additional layer of safety for crewed aircraft, new ACAS systems will play an important role in the roadmap growth epoch.

2.5 EIS – Mobile Clearance and Information Exchange

Industry supports fielding the current FAA effort to develop a digital communications approach enabling general aviation pilots to obtain a text-based expected Instrument Flight Rule (IFR) clearance electronically using a mobile device.[24] The expected departure clearance concept uses flight plan data from the FAA's System Wide Information Management (SWIM) Flight Data Publication Service and allows pilots to retrieve expected IFR departure clearance information in real time through their mobile device. This ability would reduce controller workload and frequency congestion in support of the many planned urban vertiports.

The FAA Reauthorization Act of 2024, Sec. 614 directs the FAA to identify five airports at which to conduct a pilot project to enable mobile clearance delivery. This provision received wide support from stakeholders including FAA's controller workforce.

---

[24] https://www.faa.gov/sites/faa.gov/files/FactSheet-Information-Exchange-through-Mobile-Apps.pdf

3. A Roadmap for the Evolution of Operations

Procedures, capabilities, and technologies are needed to enable full operational AAM capabilities, including remote and autonomous flight.

Full capability includes aircraft with and without a pilot/supervisor onboard sharing the same airspace in the NAS.

Following EIS, modifications to specific rules and operational procedures will enable more widespread use of this new mode of operation. Through standardization and publication of rules and guidance material, FAA working jointly with industry will evolve from LOAs and waivers to more standardized operations. Industry should support these efforts as necessary rule changes will create benefits across the entire aviation industry.

The FAA guides and determines technology evolution in the NAS and this impacts technology choices businesses make at EIS. The expected technological evolution is pictured in a general conceptual framework in **Figure 1**. EIS can take place at any point in the timeline and generally leverages existing NAS procedures and technologies, but may be augmented with the use of Letters of Agreement and waivers. In many cases, a new capability is deployed in a limited manner due to being at the start of its technological progression.

For example, the FAA utilized this progression in the roll out of ADS-B in Alaska through the Capstone Program.[25] Between 1999 and 2006 the FAA provided ADS-B avionics and GPS moving maps for participating aircraft, and deployed supporting ground infrastructure.[26] MITRE and University of Alaska found a statistically significant reduction in accidents from ADS-B, and survey results from pilots indicated a range of efficiency improvements in flight from major to marginal.[27] The resulting improvements in safety and surveillance led to the FAA's decision for nationwide deployment of ADS-B enabled surveillance in the NAS and a decision to mandate airborne equipage with ADS-B for operations in certain airspace.

More recently, the FAA in 2023 granted exemptions to develop experience and data to inform UAS operations beyond visual line of sight. [28]

---

[25] https://www.faa.gov/sites/faa.gov/files/air_traffic/technology/adsb/archival/Phase1.pdf
[26] Mike Collins, "ADS-B In Alaska 17 Years After Capstone, AOPA Pilot, August 1, 2017. https://www.aopa.org/news-and-media/all-news/2017/august/pilot/ads-b-in-alaska.
[27] Paul Herrick, Patrick Murphy, "Capstone Phase II Implementation Annual Progress Report," MITRE-CAASD and University of Alaska-Anchorage, 2005, p.44. https://www.mitre.org/sites/default/files/pdf/06_1226.pdf
[28] https://www.faa.gov/newsroom/faa-authorizes-ups-uavionix.

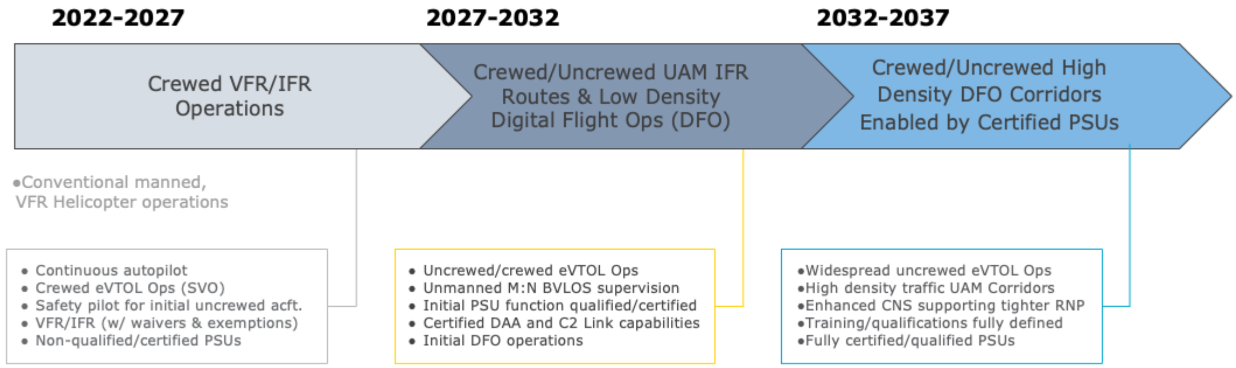

Figure 1. The roadmap to full operational capability varies by manufacturer.

Technological evolution and EIS are independent. EIS is followed by technological evolution of the NAS, which enables greater efficiencies. In Figure 1, evolution of the NAS is depicted in the chevrons and operational parameters of new aircraft are described in the bullets of the diagram.

An example of this evolution are the "UAM IFR Routes," referenced in Figure 1, which are based on existing helicopter RNAV routes. The FAA proposed in the Powered Lift SFAR that these aircraft may use helicopter RNAV procedures:

> *"The FAA also proposes to allow powered-lift operators to use Copter Procedures as defined in Part 97 if the aircraft has been type-certificated and equipped to utilize those procedures. That capability will be identified in the limitations section of the aircraft flight manual along with any other specific limitations and procedures necessary for safe operation of the aircraft."* [29]

GAMA welcomes this proposed use of Copter Procedures and encourages development of copter procedures across the United States including in additional urban environments. The Part 97 framework exists today and is an enabler for the entry into the IFR system for powered lift aircraft and will help realize more predictable operations, including for ATC.

However, the FAA concept of "corridors" needs further clarification and definition to establish airspace requirements.[30] While the concept has specific use cases, it can be associated with operations that are segregated from other airspace users. Current corridors allow VFR flight through or under Class B or C airspace, and helicopter routes are similar to corridors, defining ATC-free low altitude paths. However, the goal is enabling unsegregated access for all operators. Airspace architectures should provide net positive NAS performance, and this requires definition.

The ability of operators to progress to higher density operations during the Roadmap epoch is a function of technology, many of which are well understood and available today. Since there is no single path to full operational capability, this document describes the steps for technological evolution in the NAS and looks forward to collaboration with the FAA to achieve these goals.

[29] Federal Register, 88 FR 38949.
[30] FAA, "Urban Air Mobility (UAM) Concept of Operations: Foundational Principles, Roles and Responsibilities, Scenarios and Operational Threads, v.2.0," April 26, 2023.

3.1 Concept of Operations during NAS Evolution Roadmap

Just as EIS has unique considerations for each manufacturer, the roadmap to full operational capability will require different concepts and procedures. This document seeks to establish an organized framework. The concept of operations here borrows from the FAA UAM Concept and industry published CONOPS, to leverage existing work and common terminology.

As described above, enabling a NAS where aircraft with and without pilot onboard operate interchangeably in controlled airspace is the primary objective. The path towards remotely supervised operations may include: autonomous flight experience with a pilot onboard, unpiloted remote operations centered around gaining operational experience, and operational validation efforts utilizing all elements of autonomous operations.

It should be noted that the US military has used remotely piloted aircraft for several decades. UAS operate in the NAS every day (e.g., for border surveillance). The challenge remains fully integrating remotely piloted and remotely supervised aircraft into the NAS alongside all other traffic.

The OEMs developing UAS aircraft are utilizing varying means of conflict detection and resolution, and varying CNS infrastructure to support automation across all phases of flight to include take off, flight, landing, and taxi.

Existing aircraft-based functions are defined in regulations, industry standards, and in the means of compliance for airborne equipment certification (for UAS). Over time, those functions will transfer to onboard automated capabilities as well as ground-based systems. The transition of those functions to automation is central to this paper.

Remotely supervised operations of aircraft are possible within the near term, but require attention to these key enablers:

- Communications: PSUs, C2CSPS, and AE
    - PSUs for flight planning, conformance monitoring, and strategic/tactical routing and deconfliction services (3.2.1)
    - C2CSPs (3.2.2)
    - Ground-ground ("any to any") ATC links (3.2.3)
- Navigation
    - Build and expand low altitude instrument / TK routes (3.3.1)
    - Powered lift curved approach, landing, and take-off (3.3.2)
    - Update 14 CFR 135.165 and enable ILS precision alternatives (3.3.3)
    - Elimination of the visual segment in instrument flight procedures (3.3.4)
    - Low altitude integrated operations in Class E and G airspaces (3.3.5)
    - Define DAA operation in low altitudes (3.3.6)
    - Secondary Navigation systems (3.3.7)
- Surveillance and Other Safety Equipment
    - Adaptation of airspace regulations to encompass DAA (3.4.1)
    - DAA Expansion to Take-Off and Landing (3.4.2)

    - Vehicle to Vehicle Communications (3.4.2.5)
    - Share primary and secondary radar between industry and government (3.4.4)
    - Ground taxi solutions (3.4.5)
    - Implement ACAS-X_R (3.4.6)
- Procedures and Rules
    - Translate mature LOAs and waivers into procedures (3.5.1)
    - Digital Flight operations (3.5.2)

This bulleted list provides the outline for the contents of the next section.

3.2 Communications

Advances in real-time information sharing coupled with a distribution of roles and functions over federated service networks provide an opportunity for commercial investment to provide a highly automated, cooperative environment for flight planning and tracking. Relying on a federated service network has been envisioned and described in FAA's UAM CONOPs as an additional aspect of the future service environments, and as part of the whole NAS.

Commercial service delivery environments can assist with scalability to meet future demand challenges, sizing appropriately alongside the rapid evolution of aircraft adoption. Commercial service offerings also offer an opportunity for industry to evolve capabilities with technological innovations in cloud computing, communications, and information management.

The FAA Re-Authorization of 2024 requires that the agency establish a repeatable process for authorizing third party services. GAMA requests that the agency proceed with this effort.

Separate from the FAA enabling use of third party service providers (e.g., for PSUs) the FAA should also take the necessary steps to provide pathways to authorize use of Associated Elements[31] for UAS operations.

3.2.1 Provider of Services to UAM (PSU)

In alignment with the definition provided by the FAA, PSU entities enable safe and efficient UAM operations through a *Common Operating Picture* composed of data and analytic services that ensure airspace integrity and safety.

The *Common Operating Picture* may include information spanning airspace surveillance, aerodrome traffic, terrain and obstacle databases, real-time and forecasted weather updates, CNS performance, operating restrictions, notices to air missions, and other supplemental data sources that will enhance the situational awareness capabilities of UAM stakeholders.

[31] 14 CFR Part 1: Unmanned aircraft system means an unmanned aircraft and its associated elements (including communication links and the components that control the unmanned aircraft) that are required for the safe and efficient operation of the unmanned aircraft in the airspace of the United States.

Beyond data aggregation, PSUs will receive, evaluate, authorize, and manage across actors (e.g., aircraft operators, vertiport operators, etc.) the operational intent for all piloted and remotely piloted/supervised UAS flights as part of the core airspace services provided.

PSUs will also leverage the Operational Intent to support deconfliction functionality that will evolve from strategic planning to supporting conformance monitoring capabilities and more complex tactical self-separation cooperative practices. This evolutionary maturation will see the application of demand and capacity balancing alongside flow management ATC methods to avoid intractable separation conflicts (i.e., deconfliction). Furthermore, PSU will also provide advisory services (e.g., ground-based DAA) necessary for the higher-density operations envisioned under DFO.

A path for authorizing PSUs to perform this function, through an FAA-Industry Data Exchange Protocol using a Service Security Gateway (as shown in **Figure 2)** is needed. Additionally, an earlier path to enable PSUs to provide advisory services at or before EIS[32] may accelerate maturity and adoption of this critical enabler service.

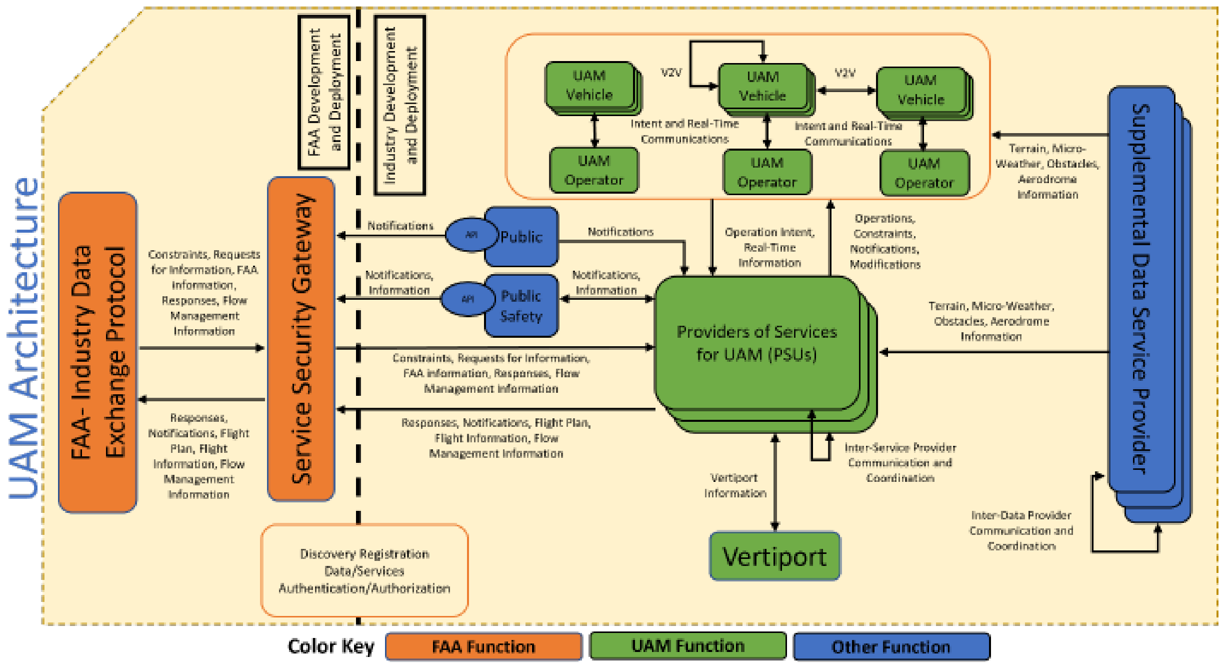

Figure 2. FAA UAM CONOPS v.2.0 Figure depicting the use of PSUs for flight filing.

3.2.2 Command and Control Communications Service Provider (C2CSP)

C2CSPs will be in service at EIS, and over time, the number, variety (local, national), and functional uses of C2CPSs will increase.

[32] For example, PSUs may provide services in non-cooperative airspace in a secondary capacity, or in shadow mode. During this period, the data collected would be used to support commercial certification application.

Many remotely supervised aircraft will have multiple C2CSPs, such as a satellite service and a local terrestrial service, specifically supporting ground taxi operations with video streams. Examples of C2CSPs and their capabilities include, but not limited to:

- AURA Network Systems,[33] a national networked C2 provider with aviation-reserved, owned spectrum
- Inmarsat, a global cell-based Aeronautical Mobile Satellite Radio Service (AMSRS)
- uAvionix, one of the first providers of UAS-reserved C-band point-to-point C2 service.

Service Providers that offer required flight services do so with AEs.

3.2.3 Ground-Ground ATC Links

There is a gap in back-up communications if a remotely piloted aircraft loses its C2 link with an aircraft. The C2 link will often be provided by more than one onboard radio, so lost link is expected to be a very rare occurrence. However, under this event, since all communication between the pilot and FAA passes through the aircraft (as described in section 2.3.1.3), if the C2 link with the aircraft is disrupted, the pilot cannot communicate with ATC. RTCA's guidance on lost link[34] recommends that a remote supervisor/pilot with lost link should contact ATC through other means. Currently the only means is a telephone call to the switchboard of the ATC facility that the aircraft was in when lost link occurred; this solution is imperfect, and other solutions are needed.

C2CSPs providing C2 links are willing and able to provide a ground network back-up. The idea of a ground network with "any to any" connectivity[35] providing a second option for ATC voice traffic has gained traction in the past year. Under the Enterprise Network Service (FENS) contract, in late 2024 the FAA will begin replacing its busiest ground voice switches serving Class B airspaces to enable IPS-compliant connectivity. Given funding, the FAA could also enable connections with third party providers at these switches, to connect with a supplemental C2CSP ground network. Enabling communications via a ground network would reduce latency, increase reliability and intelligibility for remote pilots, as well as provide a back-up pilot-ATC communication, should Lost C2 Link occur. FAA should study its available alternatives to enable ground link backups.

3.3 Navigation

The primary navigation capability in terms of avionics on board piloted and UAS aircraft will be based on wide-area augmentation system (WAAS)-enabled, IFR-approved global positioning system (GPS) to support terminal and enroute procedures. The industry is looking to primarily leverage the existing navigation policy framework in the midterm. Conducting operations in low

[33] AURA will offer Service Level Agreements (SLAs) that ensure coverage for all the operator's planned routes, including emergency landing spots and alternate destinations for weather deviations.
[34] RTCA, *Guidance Material for Lost C2 Link UAS Behavior*, DO-400, June 2023.
[35] "A 2035 Vision for Air Traffic Management Services - Preliminary," MITRE, May 2020. https://solutions.atca.org/wp-content/uploads/2020/09/Preliminary2035VisionforATMService-PRS.pdf

altitudes may drive FAA and industry to invest in low altitude navigational infrastructure, enabling low altitude operations, using DAA to assist in deconflicting low altitude operations.

3.3.1 Build and Expand Low Altitude Instrument / TK Routes

Instrument flight procedures (IFPs) are standardized maneuvers for performance-classified aircraft to assure aircraft positioning for safe and orderly flight during approach and departure. For a given airport, the IFP is tailored to the runway, accounting for terrain and ground systems, to create Terminal Instrument Procedures (TERPS)[36]. Some AAM vehicles being introduced are capable of performing like a helicopter.

Instrument procedures for helicopters are very rare in the US, and eVTOLs in particular will need low-altitude, instrument routes, including under 3000 ft AGL. Stakeholders have already begun to highlight the need for new IFP/TERPS design criteria, as noted by work published by NASA and industry.[37,38, 39] A TK (helicopter IFR RNAV) route can provide an approach or departure path to precision VTOL landing and take-off sites.

3.3.2 Powered Lift Curved Approach, Landing, and Take-Off

A number of unique elements of AAM need to be incorporated in IFPs to gain improvements in efficiency especially with the obstacles in urban environments. When it comes to AAM missions, only approach and departure procedures need to be designed in tailored Terminal Procedure design. It is unlikely that there will be an AAM equivalent for lengthy Standard Instrument Arrival Procedures, as the altitude and mission ranges will not allow for it. A NASA-Joby study researched an omni-directional terminal airspace architecture, to form a framework for application to potential airspaces, to design all-weather AAM TERPS. The operational airspace is cone-shaped, surrounded by a cone-shaped obstacle buffer[40] (see **Figure 3**.)

The landing and take-off procedures were designed inside the operational cone. Three approach and departure paths with three potential gradients (5, 8, and 12 degrees) were designed, utilizing radial approach paths to conserve airspace. While a 12 degree landing in a fixed wing feels very fast, 12 degrees is very conservative in a VTOL that can do a 90 degree approach. In addition to one engine out procedures, transition points, go-around procedures, battery temperatures, loading, passenger comfort,

---

[36] Today several FAA Orders define the standards related to instrument procedures, and are encompassed by the colloquial term TERPS. https://www.faa.gov/documentLibrary/media/Order/Order_8260.3D_vs3.pdf
[37] UAM IFP Design and Evaluation in the Joby Flight Simulator - https://ntrs.nasa.gov/citations/20230003478
[38] National Campaign Airspace Automation Tabletop - https://ntrs.nasa.gov/citations/20230000620
[39] Missed Approach Procedures in AAM: Conceptual Exploration - https://ntrs.nasa.gov/citations/20230007215
[40] David Zahn and Wayne Ringelberg, "Urban Air Mobility (UAM) Procedure Design and Flight Test Evaluation Methodology," Society of Experimental Test Pilots Symposium 2023.

and noise levels were incorporated, producing experimental terminal approach plates and ARINC 424 flight management computer coding.

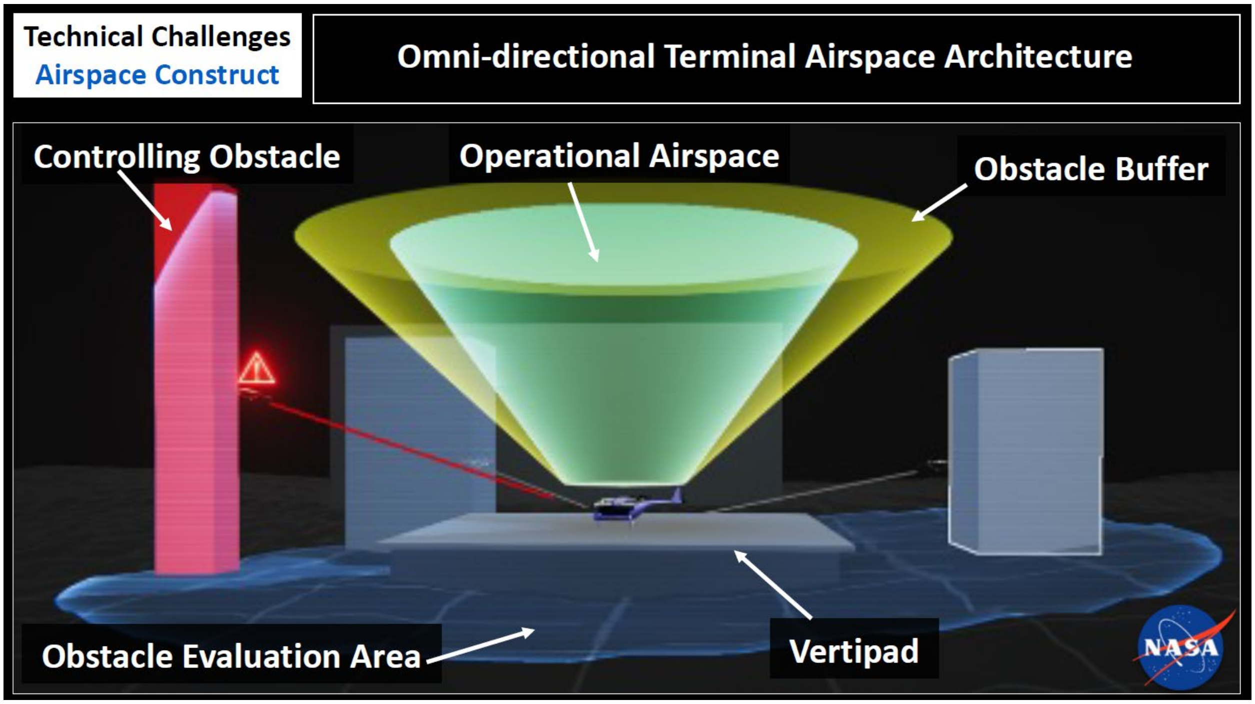

Figure 3. NASA-Joby study with Operational airspace inside an obstacle buffer airspace, from Zahn and Ringelberg.

Vertiports co-located with airports need to account for standard traffic flows and patterns in the vicinity of that airport to ensure a proper integration with legacy operations. To that extent, IFP design needs to account for those factors to ensure proper use of airspace and integration with standard traffic flows and to avoid obstacles. The omni-directional operational airspace cone designed by Joby and NASA was shown to fit within the terminal airspace of Marina Municipal Airport (OAR) with an equivalent level of safety for instrument flight.

3.3.3 Update 14 CFR 135.165 and Enable ILS Precision Alternatives

Curved approaches are needed to access vertiports with multiple surrounding obstructions. To enable curved precision approaches, CFR requirements surrounding ILS need to be changed. ILS operates on an elongated straight-in approach and is not suitable for a curved approach. The regulation needs to be adapted to allow for other robust precision navigational technologies, such as GPS-based augmented landing systems, Autoland, and novel vertiport-based precision landing systems. Extant alternatives to ILS accepted by the FAA and prescribed in 14 CFR 135.165 include VOR/DME and precision lighting systems, all of which would be impossible to apply to curved approaches.

VOR and DME provide non-precision approach guidance. DME provides distance to airport for ILS approaches. VOR/DME RF signals may be signal-denied at low altitude and obstructed approaches, such as a low approach, or in a highly obstructed environment. Precision Approach Indicator (PAPI) systems with marker beacons provide straight-in precision approaches. PAPI and Visual Approach Slope Indicator systems both rely on line-of-sight from the aircraft, and would be difficult if not impractical to use on a remotely supervised aircraft.

Existing airports are served with GPS approaches as well as VOR/DME and ILS. The NASA-Joby approach plates used GPS-based radius-to-fix approaches, which could be tailored to fit in the airspace of traditional fixed wing airports that host vertiports. For example, a corridor based TK (helicopter IFR RNAV) route may use a low-altitude curved radius-to-fix approach in Class B airspace, perhaps using underutilized stub runways to touch down.

Potential precision landing sensor systems to support curved and steeper landing approaches include:

- Precision GPS systems such as satellite-based Wide Area Augmentation System, and the Ground Based Augmentation System (GBAS) Landing System (GLS). Avionics with TSOs are available.
- An electro-optical guidance grid that works with a short range data link to an aircraft. As an example, the GE Precision Landing System is designed for rotorcraft oil platform landings and accommodates curved approaches. It lacks a TSO, and FAA authorization for U.S. airport use is not known.
- Autonomous aircraft-ground-based sensor-based precision landing systems are a potential solution, but are not yet described in standards, and not yet certified.
- Aircraft-based doppler-lidar system exists on spacecraft, is not developed for commercial use, not yet described in standards, not yet certified.
- A ground-based positioning, navigation and timing (PNT) network could augment a GPS landing system with precision corrections. Such a system is not yet described in standards, and not yet certified. Both AAM and other GPS-reliant systems would benefit from such a system.

Alternative PNT (A-PNT) is not required for supervised flight at EIS. Alternatives such as DME and ILS can be used. However, legacy precision landing systems were created around straight-in approaches, and ILS and DME are not well suited for curved and obstructed approaches. In the case of supervised flight using curved or obstructed approaches, A-PNT is also attractive to mitigate GPS outages.[41]

3.3.4 Elimination of the Visual Segment in Instrument Flight Procedures

AAM operations will leverage existing procedures as much as possible at EIS, but as new aircraft configurations such as VTOLs enter the market, new procedures and evaluation criteria, especially for urban vertiport locations, will be necessary. IFPs for helicopter operations are uncommon and will always require a visual segment, which is a limitation to remotely supervised operations. Elements of both fixed-wing segments and visual flight segments are traditionally adopted into the design features of

[41] The FAA's Navigation Roadmap places significant resources on multi-function, multi-constellation GNSS to address reliability and availability.

IFPs and written into the TERPS. Elimination of the visual segment to accommodate all-sensor based approaches and departures is needed, when the IFP is developed and in corresponding regulations.

3.3.5 Low Altitude Integrated Operations in Class E and G Airspaces

There is a lot of airspace that is not A, B, or C. Remotely supervised aircraft will be using Class E and G airports, and will need to traverse class E and G airspace. There is the potential for remotely supervised aircraft to be operating in the same airspace as VFR aircraft, and the VFR aircraft may not have a full suite of avionics to enhance detect and avoid. Onboard radios are not required for VFR flight in Class E or G. Class E and G are the airspaces most likely to lack radar and other surveillance coverage.

When an IFR flight requests services in a non-radar Class E airspace, the air traffic controller can provide only procedural separation from other IFR aircraft. If the prevailing conditions are visual, there may be VFR aircraft in that airspace that may not be detected by ATC. For a remotely piloted aircraft, systems such as DAA sensors will be the only way to detect non-cooperative aircraft in non-radar airspace.

Beyond the near-term time period, remotely supervised aircraft fleets may achieve dense operations, particularly if an operator of a fleet of remotely supervised aircraft opens a base of operations at a particular airport. If this base is established at a Class G or E airfield, it may become desirable to provide additional means of ensuring safety between remotely supervised aircraft and other aircraft, particularly aircraft without TCAS, ACAS, or traffic information displays on board.

Further, the altitudinal separation by direction of travel (Part 91 flight rules subpart B) does not apply below 3000’ AGL. Urban Air Mobility is envisioned to host multiple directions of travel below 3000 ft. AGL. As traffic increases below 3000 ft AGL, safety and efficiency would be enhanced by increased coordination. Potential solutions include defined flight routes, added radar, and procedural separation. A sizeable portion of airspace below 3000 ft in an urban environment will not be covered by surveillance, and may be ATC-voice limited as well, so means for cooperative separation must be ensured. Additional resources and time will be required to conduct discussions with new commercial operators, to enable growth in urban environments. Key among cooperative separation technologies are those previously discussed: ACAS, ADS-B, DAA, TCAS, and V2V as well as legacy Secondary Surveillance Radar (SSR).

3.3.6 Define DAA Operation in Low Altitudes

DAA is the capability to perform Remain Well Clear (RWC) and Collision Avoidance (CA) against both cooperative and non-cooperative aircraft. Radar, electro-optical, and infrared sensors are used to detect non-cooperative aircraft and the DAA processor provides avoidance advisories.

DAA works with or without transponders while TCAS/ACAS works on a cooperative interrogation basis. TCAS/ACAS detects other transponder equipped aircraft.

DAA standards[42] define design and operation in concert with TCAS II/ACAS 7.1, its replacement ACAS, and Mode C and Mode S transponders, or without these other avionics onboard.

A DAA processor has both a pilot-alerting mode and an automatic mode in cases in which a collision is imminent and pilot action would not be timely. DAA processors can be onboard the aircraft, ground-based, or in the remote pilot station. As an example, one class of DAA airborne avionics was designed to incorporate ground-based surveillance systems as primary or contributory sensor input. A PSU will use GBSS among other systems to provide sequencing and conflict avoidance or resolution.[43] DAA standards have been written and compliant technologies are being developed. DAA can be an enabler of digital all-weather low altitude operation.

3.3.7 Secondary Navigation Enhancements

At EIS, most AAM manufacturers state an intent to equip with navigation equipment to meet Required Navigation Performance (RNP) 0.3 en route, and to use or progress to RNP 0.1 for approach and departure. Given that these RNPs depend primarily on GPS, the risk of spoofing and jamming must be mitigated.

In some areas of the urban environment, existing VOR and DME are blocked by obstructions such as buildings, bridges, and terrain, which would be a problem when conducting landing and take-off among tall buildings. In the densest urban environments, no additional DME/ L-band frequencies are available.[44] GPS also suffers from signal blockage in urban environments, so secondary navigation capabilities, such as land-based differential GPS, may need to be implemented for all-weather operations.

Numerous back up technologies are available, including aircraft-based sensors (lidar, sonar, radar, visual, signal mapping) fused with spatial recognition software, ground-based position navigation timing networks (which would need an RF signal to communicate), and utilizing comm channel phase or doppler shift as a navigation source. Work is needed to develop backups and standards for secondary navigation systems that work as confirmation and supplements.

3.3.8 Strategic Deconfliction for Low Altitude Flights

Low altitude airspace often lacks radar coverage and in many areas air traffic does not or cannot provide separation services. As maintaining ATC service at every public airport in the US would be prohibitively expensive, industry is advocating procedural and technological changes to allow RPAS operations in areas without ATC coverage. To address this challenge, PSU digital services associated with collaborative

---

[42] DAA systems are standardized in RTCA *Minimum Operational Performance Standards (MOPS) for DAA* (DO-365), *MOPS for Air-to-Air Radar (ATAR) for Traffic Surveillance* (DO-366), *MOPS for Ground Based Surveillance Systems* (DO-381). Commercial avionics were adopted by the FAA in Technical Standard Orders TSO-C211 for DAA and TSO-C212 for ATAR.

[43] Nouri Ghazavi, "UAM Airspace Management Demonstration," FAA REDAC Report, March 14, 2023. https://www.faa.gov/sites/faa.gov/files/REDAC-NASOps-03142023-508.04-Spring-2023-REDAC-NAS-Ops-UAM-Airspace-Demo.pdf

[44] Department of Transportation Section 374 report and hearings, 2019.

intent and surveillance data may provide a sufficient level of service to support scalable operations in these areas.

Beyond procedural means and above-mentioned cooperative separation technologies, PSU capabilities could provide increased airspace situational awareness by extending SSR capabilities through the deployment of additional surveillance services. In line with PSU capabilities discussed herein (3.2.1), the resulting Operating Picture would in turn support strategic planning, flight intent conformance monitoring, and tactical deconfliction cooperative methods – capabilities that would support scalable operations in this airspace.

3.4 Surveillance

Mid term operations will continue to rely on (non-cooperative) radar and (cooperative) ADS-B for air-to-ground surveillance. UAS operators plan to leverage surveillance data as part of their safety cases and to support certification. Industry supports expansion of both non-cooperative and cooperative surveillance infrastructure.

3.4.1 Adaptation of airspace regulations to encompass Detect and Avoid (DAA)

The FAA BVLOS ARC recommended reviewing and updating right-of-way regulations to enable a digital means to detect an aircraft in addition to the responsibility of all pilots to see and avoid other aircraft.[45] Established legal interpretation of "pilot see" language refers to human eyes' perception.

GAMA, jointly with the Aircraft Electronics Association (AEA), Aircraft Owners and Pilots Association (AOPA), Experimental Aircraft Association (EAA), Helicopter Association International (HAI), National Business Aviation Association (NBAA), and National Agricultural Aviation Association (NAAA), in 2023 as part of a filing in the Beyond Visual Line of Sight (BVLOS) rulemaking docket endorsed the FAA advancing an amendment to 14 CFR 91.113 to enable detect and avoid as a means by which an pilot or aircraft operator meets his/her responsibilities to observe right-of-way rules. The associations also encouraged the FAA to update the hierarchy section of the right-of-way rules to ensure all types of aircraft are fully considered.

In addition to regulatory endorsement of digital sensing and remotely supervised flight, remotely supervised flights must be enabled to have the same privileges and responsibilities as pilot-onboard

[45] For example, FAA should make the following additional change to the right-of-way regulations), 91.113 (new text in bold italics: '(b) ***General.*** When weather conditions permit, regardless of whether an operation is conducted under instrument flight rules or visual flight rules, vigilance shall be maintained by each person operating an aircraft so as to see***, or detect using a means approved by the Administrator,*** and avoid other aircraft. When a rule of this section gives another aircraft the right-of-way, the pilot shall give way to that aircraft and may not pass over, under, or ahead of it unless well clear." See the FAA BVLOS ARC Final Report, March 2022, for the joint industry letter.

aircraft. Consistent with a recent EASA Opinion,[46] remotely supervised flights should operate with parity in the digitally enabled NAS, including:

- Onboard automation and digital sensor use in flight, in place of pilot sensing, with approval under current regulations, with the expectation that future rulemaking may be required.[47]
- Ability to fly without legacy onboard see-and-avoid, and relying on onboard/offboard DAA systems.
- Enable all-weather operations without ATC separation and navigation for low-altitude service volumes (below 10,000 ft AGL). This is consistent with the FAA UAM CONOPS V.2,[48] in which communications with ATC are suspended in the UAM service volume (“corridor”), which traverses or adjoins class B/C/D airspace. Communications with ATC are only required when exiting the “corridor” into controlled airspace (e.g., contingency scenario.)]
- Reduced and variable separation distances, using a performance-based approach for distance.

3.4.2 Establish DAA Standards for Take-Off and Landing and Non-Towered Airports

Pilots and controllers are assisted in carrying out their responsibilities for maintaining separation with other aircraft by several systems that detect aircraft and provide location information. The existing systems are being enhanced and new systems are being added to enable digital awareness:

- ACAS is being enhanced to provide more accurate avoidance assistance encompassing additional aircraft maneuvering profiles;
- ADS-B IN (i.e., “receive”) provides the pilot or remote pilot aircraft operator with a traffic picture through applications such as Cockpit Display of Traffic Information (CDTI); and
- DAA provides sensor-based detection onboard the aircraft and enables remote piloting.
- Additionally, FAA and industry have explored the introduction of tactical intent information. The objective of aircraft providing tactical intent information is to assist in deconflicting flight paths, reducing the need for DAA resolutions.

---

[46] European Union Aviation Safety Agency, “Opinion 03/2023”, developed in task RMT.0230 Volume II, European Plan for Aviation Safety 2023-2025, and released in Notice of Proposed Amendment 2022-06. https://www.easa.europa.eu/en/document-library/opinions/opinion-no-032023; specifically the draft rule “Draft Commission Delegated Regulation (EU) …/…” amending Regulation (EU) No 748/2012 as regards the initial airworthiness of unmanned aircraft systems subject to certification and Delegated Regulation (EU) 2019/945 as regards unmanned aircraft systems and third-country operators of unmanned aircraft systems.

[47] Referring to FAA plans for future rulemaking, as called out in the FAA UAM CONOPS: "Automated Flight Rules (AFRs) – Refers to rules, applied within UAM Corridors, which reflect the evolution of the current regulatory regime (e.g., VFR/IFR) and take into account advancing technologies and procedures (e.g., Vehicle-to-Vehicle [V2V] and data exchanges). Under defined conditions, the systems/automation may be allocated the role of the “predetermined separator.”

[48] FAA, “Urban Air Mobility (UAM) Concept of Operations: Foundational Principles, Roles and Responsibilities, Scenarios and Operational Threads, v.2.0,” April 26, 2023. https://www.faa.gov/sites/faa.gov/files/Urban%20Air%20Mobility%20%28UAM%29%20Concept%20of%20Operations%202.0_0.pdf

DAA has been defined for operation above 400 ft AGL, with limited applicability during take-off and landing. RTCA is developing guidance on use of DAA in take-off and landing operations. However, there is a procedural and regulatory gap for aircraft depending on DAA when in take-off or landing phases, particularly at non-towered airfields. Additional work in use of DAA at non-towered airfields needs to be continued.

A well-functioning DAA system must consider all aircraft. Additional systems for detecting and deconflicting aircraft of different sizes are discussed in the sections that follow, particularly under "DAA Expansion" and "Vehicle to Vehicle Communications."

3.4.3 Vehicle to Vehicle Communications

For efficiency and safety in congested low altitude operations under Class B and C airspaces, a means of providing aircraft intent information should be developed and implemented. Tactical intent encompasses the next five minutes of planned flight, providing an update over an aircraft's flight plan, which is considered strategic intent.

Use of traffic awareness can also enable distributed traffic management under procedural separation.

SUAS and larger AAM vehicles are evolving separate means of deconfliction. There is a gap in the detection and avoidance systems between the two groups. Since sUAS operate within 400 feet of ground level, operating near heliports and airports only by exception, sUAS and AAM aircraft should be separated by airspace. They should not be in the same airspace at the same time. However, aviation safety is built on ensuring – not assuming – separation. The gap in sUAS to large AAM vehicle coordination was a key factor in advocating for Vehicle to Vehicle (V2V) Communications.

There are multiple ways of providing intent information, depending on the traffic considered:

- For AAM and commercial aircraft, ADS-B with tactical intent is an option.[49]
- Between sUAS and larger aircraft, including AAM, V2V is an option.
- Between sUAS, a lightweight V2V is an option.
- Ground-based surveillance and separation technologies have been proposed for sUAS and for remotely piloted AAM. An additional alternative method is industry-supplied surveillance systems, which would be provided on a PSU-like basis or as a contract arrangement to provide data to FAA, which would then be shared to industry operators.

Remote ID is not designed for separation. Remote ID[50] (R-ID) was created in order to facilitate sUAS identification, particularly around airports, in order to mitigate rogue UAS encounters. While some researchers have studied the possibility of using sUAS' R-ID as a method of coordinating and

[49] ADS-B may also provide a crucial tool for service-volume flow efficiency as operations increase, if tactical intent information is added to ADS-B. Flight intent was proposed as a field within ADS-B, but the proposal was deferred, based in part on competing interpretations and needs for intent. Flow efficiency in congested airspace is increased when ADS-B is used to maintain desired spacing between aircraft: Osequera-Lohr, R., Lohr, G., Abbott, T. and Escheid, T., "Evaluation of Operational Procedures for Using a Time-Based Airborne Inter-arrival Spacing Tool," NASA/TM- 20040085756, Hampton, Virginia, January 2002.

[50] CFR Part 107

separating aircraft, FAA prohibits the use of R-ID for separation, as R-ID data has insufficient reliability. However, R-ID may be used in an advisory capability, particularly in congested airspace such as around airports and vertiports, to indicate the presence of sUAS within a certain range, akin to a point-out.[51]

V2V, also called Aircraft to Aircraft cooperative communication, was proposed by GAMA as a means to bridge the gap between uncrewed and crewed aircraft situational awareness, for strategic deconfliction, in 2021. The concept was further developed in a follow-on effort at RTCA, with a more detailed concept of operations, in 2022. In 2022, FAA commissioned MITRE to study the ground-based applications of such a concept.

V2V progress has slowed, for several reasons:

- The primary problem, that aircraft without a pilot onboard could not use ADS-B for cooperative situational awareness, has been eased with the FAA's determination that large RPA would be able to use and should use ADS-B. This reduces but does not eliminate the problem gap.
- There is no allocated spectrum for V2V. Good systems engineering practices indicate that a message set, a range, and the design number of aircraft using the system need to be in harmony with the size of the allocated spectrum. Disagreement among stakeholders as to the message set and the users remains; thus, the spectrum needed remains undecided and unallocated.
- Related to the first two points, members of the commercial sUAS community (including small package drone delivery) have stated their need to use V2V for strategic deconfliction. The request has merit. Some parties have proposed highly frequent broadcast protocols, which would require relatively more spectrum, particularly with very high numbers of aircraft. This use case is distinctly different than the large-aircraft proposal. Added complexity to the V2V use case has not accelerated a solution.
- There is enthusiasm in FAA for parasitic use of large-aircraft V2V as an inexpensive way to conduct surveillance, and thus a certain disadvantage to consideration of using V2V for sUAS.
- There are no quantitative studies establishing the benefits of V2V.

There needs to be agreement among the FAA, sUAS, and larger aircraft operators, both remotely supervised and piloted, on the potential use of V2V. This effort should also consider the FAA's original intent for surveillance of sUAS that was part of the Remote ID decision process. SUAS (sUAS) have small cross-sections and are difficult to detect without their participation in collaborative systems. For greater safety, the ability to detect and avoid smaller aircraft needs to be improved.

3.4.4 Share Primary and Secondary Radar between Industry and Government

Some operators' safety cases are enhanced by the presence of an independent surveillance system, particularly for aircraft that have no pilot onboard. Conversations with FAA representatives indicate there is interest in this area and independent surveillance could be required either in certification or in

[51] NAS protocols are based on sUAS giving way to larger vehicles.

operation for RPA. There are potential benefits of shared surveillance to all aviation for low visibility operations and at non-towered airports, through the use of enhanced traffic awareness.

Given this mission need, there are several methods to achieve additional levels of independent surveillance. One method would be to share real-time information from FAA-owned Primary (PSR) and Secondary radar (SSR) to operators.

The FAA Air Traffic Organization (ATO) is evaluating the mechanisms through which PSR and SSR-derived safety-critical data could be made available to airspace users more widely. The effort, at present, is working through technical (e.g., cybersecurity), law enforcement, and national security (e.g., sensitive military operations) challenges requiring interagency collaboration. While ATO has stated this effort is a priority, dedicated programmatic resources have not been made available.

Security modifications require establishment of a trusted industry entity to receive the data. No funded program exists to achieve this.

Alternatively, the Traffic Information Service Broadcast (TIS-B) is an extant way through which the SSR information is shared with aircraft today. FAA planned to retire existing TIS-B services when sufficiently high ADS-B equipage is realized. However, enhanced TIS-B is a proposal to continue and enhance TIS-B to include PSR.

Recognizing both the benefits and the challenges of making these data available to the broader aviation community, a call for increased government collaboration to improve the safety of the NAS is put forward. Along these lines, industry commits to working with the government to ensure that approved organizations and personnel use these data safely and responsibly.

3.4.5 Ground Taxi Solutions

A system of aircraft-mounted taxi cameras, radars, communications and procedures for remotely piloted/supervised aircraft is being defined through minimum operational standards (MOPS) and Minimum Aviation Systems Performance Standards (MASPS) at RTCA. In MASPS and MOPS for Automatic Taxi Navigation Systems (ATNS) in RTCA SC-228, operating procedures for the final approach, when the aircraft senses and identifies whether the runway is clear of aircraft and objects, are being discussed and written into the standards.

Issues at the intersection of lost link and foreign object debris, aircraft or ground vehicles appearing where not expected are analyzed and resolved with procedures at taxiways, runways, and hold short lines. Resolution of low-likelihood scenarios often relies on high quality video from the aircraft being fed back to a remote pilot for decision-making. The C2 link for ground taxi faces multiple obstructions from aircraft, trucks, buildings, fuel tanks, etc., and antenna siting is limited by safety (height) or ownership. Remotely piloted ground taxi relies on high bandwidth video through a customized C2 connection. The bandwidth needed for video is three orders of magnitude higher than that needed for command and control, and two orders of magnitude higher than needed for ATC voice relay.

Put differently, a Mbps-sized connection could carry one video feed from one aircraft, or telemetry and position from hundreds of aircraft and all the voice traffic from multiple ATC sectors. Allocated frequency to support aircraft ground taxi video may come from commercially retained 5G cellular connections or from Aeronautical Mobile Airport Communication System (AeroMACS, 5000-5030 MHz and 5091-5150 MHz). Particularly where numerous remotely piloted aircraft are expected, a separate capability of airfield-based video multicast to pilot-supervisors may provide more efficient spectrum utilization. In addition, airfield-based video can be coupled with automated alerts that signal remote pilots and ATC when undirected or erroneous aircraft movement occurs, such as landing on the wrong parallel runway, or crossing a hold short line. The provision of multiple video views on the airfield would provide supervisory situational awareness superior to the single aircraft camera view.

3.4.6 Complete ACAS -X_R

Safety is ensured in the NAS with overlapping means. As an example, 14 CFR 91.113, right of way, requires pilots onboard ensure safe separation using see-and-avoid. ATC instruction provides separation assurance when visibility and aircraft speed require augmentation on top of see and avoid.

TCAS II/ACAS is an enabler of remotely supervised operations. Recent work to further develop ACAS has focused on better encompassing the maneuvering capabilities of powered lift aircraft and rotorcraft and well-clear distances for UAS. ACAS incorporates eight classes of DAA equipment, differentiated on the basis combinations of the sensors used by the DAA, which can include: ADS-B, simple transponders (Mode C and UAT), radar, electro-optical/infrared, and ground-based sensing systems.[52] As an airborne avionics system, acting independently of ATC, ACAS mitigates the risk of midair collisions when other safety implementations have failed.[53]

ACAS X_O/X_A are the baseline variants succeeding TCAS I. ACAS Xo includes use in closely spaced parallel approaches, avoiding generating nuisance alerts.[54] Both take advantage of dynamic programming technologies, enabling more complex algorithms and operation, which were not available when TCAS I was developed. In addition, ACAS Xu (u = uncrewed aircraft) was developed for RPAS; its extension, ACAS sXu is intended for small, uncrewed aircraft, defined formally as RPAS with wingspans less than 50 ft.,[55] potentially suitable for UAM operations. ACAS Xu includes algorithms not only for ascending and descending avoidance maneuvers, but also horizontal maneuvers appropriate to slower speeds and smaller size of small UAS.

TSO-219A describes approval for ACAS-X_A and ACAS-X_O; the version tailored to rotorcraft, ACAS-$X_{R,}$ is expected to follow. The FAA should fund and support the complete development, standardization, and deployment of ACAS-X_R for rotorcraft, powered-lift, and fixed-wing aircraft.

---

[52] Remote ID broadcast is specifically excluded from being used as a collision avoidance sensing device. Vehicle-to-vehicle communications is acceptable but the V2V system is undefined.
[53] ACAS Guide -Airborne Collision Avoidance Systems - Eurocontrol March 2022 (https://www.eurocontrol.int/sites/default/files/2022-03/eurocontrol-safety-acas-guide-4-1.pdf [eurocontrol.int])
[54] Standards published as RTCA DO-385 (Sept. 2018) and EUROCAE ED-256 (Oct. 2018). Note that ACAS II is considered equivalent in function to TCAS II. ACAS X uses improved algorithms (over ACAS II) to reduce nuisance advisories, particularly in rapid climb-out.
[55] ACAS Guide -Airborne Collision Avoidance Systems - Eurocontrol (n.31), March 2022

3.5 Procedures and Rules

Evolution of the NAS relies not only on technological innovation, but equally on procedural adaptation. Procedural change is often embarked on in a step-by-step trial basis, gaining experience with innovations, and eventually refined into implementable policy. As technology becomes available, these procedures may be further supported by, or supplanted by, emerging digital flight operations.

3.5.1 Mature LOAs and Waivers Transition to Standard Operating Procedures

Consensus is often built by accepting incremental changes that have been tried out for some period. Many of the requests by industry in this roadmap have been discussed with FAA or invoked in the FAA UAM CONOPS, such as V2V, PSUs, PSR & SSR data exchange, and collaborative separation rules.[56]

Regulators, including FAA, have communicated recently that the agency is seeking data and experience by way of solicitations for feedback about exemptions. The mechanisms identified within the exemptions granted by the FAA is expected to inform rulemaking or other policy developments that would more widely provide for integration of these new operational capabilities.

The FAA has the power it needs under waivers and authorizations to begin adopting precepts of DFO. DFO is proposed to begin some of those proposed adaptations.

3.5.2 Digital Flight Solutions

Digital Flight Operations (DFO) is a proposed concept to allow UAS to operate under a new paradigm that draws from both IFR and VFR. DFO embraces the separation methods and technologies commonly found in IFR flight for terrain, obstacle, and other aircraft avoidance for DAA, but applied to distributed decision-making (aircraft based instead of ATC-guided) and communally agreed or well-clear separation (less than the IFR imposed 3 miles), in common with VFR. The combination allows the introduction of non-segregated UAS while obviating human constraints on density and congestion. Some of the IFR elements and structure reflected by DFO include:

- Operational Picture – extends primary/secondary and ADS-B information used by ATC alongside additional V2V and conspicuity sources to provide an Integrated Operating Picture across participating DFO aircraft and reflecting position of all known traffic (participating and non-participating) as well as intent (when available).
- Strategic and Tactical Services – leverages conspicuity, shared situational awareness, and established cooperative based rules, to inform participant deconfliction decision-making. Strategic and tactical methods extend IFR flight planning, sequencing, and separation methods.

[56] FAA UAM CONOPS v 2.0.

- Weather Minima – the combination of an Integrated Operating Picture and Strategic/Tactical Separation capabilities, alongside onboard instruments, allow DFO aircraft to operate in weather minima conditions comparable to that of IFR operations.

The concept of DFO relies on CNS services and procedural innovations. Procedural innovations would allow aircraft to fly in non-segregated service volumes under instrument meteorological conditions without use of air traffic control separation and navigation services, and the formulation of procedures such as autonomous ground taxi and lost link.

Prerequisite CNS services that enable the concept of DFO include C2CSP, DAA, and PSUs. IFR-type flight plans used with remotely supervised aircraft today remain an essential part of the solution, to plan and communicate the aircraft's planned route of flight. RTCA has published a white paper detailing DFO proposed concepts.[57]

The implementation of digital flight operations enables additional communication and collaboration functions for all air traffic, which is needed in an increasingly varied NAS.

To advance DFO, the FAA can take specific actions in the near-term, which include:

- Incorporate Digital Flight into FAA's vision for a future NAS (NAS 2040) and establish it as a priority for the agency.
- Increase collaboration with NASA on R&D efforts, to include defining cooperative operating practices through technology demonstrations and experimentation.
- Utilize near-term DAA developments and operations to validate parts of a Digital Flight ecosystem.
- Continue partnering with SDOs to develop digital flight standards where interoperability or standards for new equipment are necessary.
- Enhance the FAA's role at ICAO to be a leader in developing a new set of flight rules, even if at a high-level. This will enable the FAA and stakeholders to begin work on more detailed guidance material and standards as technologies mature.

[57] Forum for Digital Flight: Enabling Future Operational Concepts in the National Airspace System for All Airspace Users (https://www.rtca.org/news/digital-flight-report/)

4. Mature State

The previous section summarized requests and needs from the EIS and growth epochs for AAM, which are necessary but not sufficient for building a mature AAM system over the next decade. Considering the previous section serving as the near-term to-do list, this section provides a framework for future actions. The guiding principles of this roadmap include a) enabling access to all airspaces, b) applying systems engineering requirements management processes, and c) employing performance-based solutions, all with the aim of the roadmap to remotely piloted aircraft and autonomy.

Developing the future roadmap calls for the assessment of performance-based standards. Topics that require resolution to achieve full operational capability require more research, analysis, and consensus building than could be addressed in this initial document. These issues will require substantial collaboration by industry and government.

4.1 Operational Rules

For increasingly autonomous aircraft operating in all airspace, especially in terminal airspace (e.g., Terminal Radar Service Areas and Classes B, C, and D), operating rules are needed that benefit from the unique operating capabilities of these aircraft. Ensuring access for all aircraft, fixed wing and VTOL, autonomous and less instrumented, will be complex. These requirements need to address equipage, pilot training requirements, and airspace architecture and procedures for low altitude performance-based operations in service volumes that are supported by advanced CNS systems. These advanced CNS systems would include digital communications (including V2V, digitized voice over IPS to ATC), alternative supplementary navigation (independent from GNSS), and alternative supplementary terrestrial and airborne surveillance systems. This definition may include a requirement for layering of these systems for total reliability.

As demand increases, airspace throughput will benefit from modified separation standards in these performance-based volumes to become a cooperative agreement instead of an absolute distance specification.

4.2 Demand-Capacity Balancing

Similar to centralized ATM demand-capacity balancing (DCB) methods that increase traffic flow efficiency in the airspace today, a highly successful future AAM will leverage DCB services offered by PSUs as part of the strategic planning capabilities supporting aircraft operating under DFO along destinations or routes in high demand. These DCB methods, coupled with CNS capabilities and airspace architectures/procedures (e.g., reduced separation service volumes), are a method for safely and efficiently managing increased capacity. During initial AAM operations we assume that the filing of flight plans with the FAA provides initial demand/capacity balance.

We assume that PSU filed flight plans will leverage the concepts of operational intent and trajectory-based operations. Current industry efforts reflective of PSU-enabled DCB are happening under NASA's Air Mobility Pathfinders (AMP) project, ASTM WK85415 – UAM Interoperability working group, as well as Single European Sky ATM Research (SESAR) projects such as EUREKA (European Key solutions for vertiports and UAM) that aim to include vertiports in the capacity management equation.

Understanding that DCB services for AAM will need to be operationally integrated with current legacy systems, close coordination with the FAA is essential for the successful validation and deployment of these PSU supported capabilities.

4.3 Spectrum

The NAS faces several challenges regarding the availability of RF spectrum for data and voice communications, particularly looking towards 2030. These challenges are crucial, as RF spectrum is a finite resource and essential for safe and efficient operations. Key challenges include reserving spectrum for the increased levels of aviation coordination and cooperative separation, and doing so in coordination with international partners. Mixed use spectrum will not be appropriate for many aviation applications, as some applications require a greater assurance of freedom from interference. The requests for coordination channels (such as V2V, DAA, PNT) represents the demand for increasing coordination across the NAS for all operators, to enable scalability and flexibility.

As the aviation community moves forward with increased coordination among aircraft and integration of remotely piloted aircraft, securing communications from malicious interference, denial of service, and other bad actors moves from a good idea to absolutely essential. Technological innovation in spectrum-efficient coding goes hand in hand with the need for encryption and authentication. All this must be accomplished in a way that is affordable for airspace users and all spectrum users.

Addressing these challenges requires a coordinated effort among regulatory bodies like the FAA, international organizations like ICAO, industry stakeholders, and technology developers. It will involve balancing current and future spectrum needs, advancing technological solutions, and ensuring that safety and efficiency remain paramount in AAM operations.

4.4 Dynamic Trajectory Based Operations

Dynamic Trajectory-Based Operations (TBO) could play a pivotal role in managing the efficiency of the NAS. Dynamic TBO allows for real-time adjustments to flight paths based on various factors like weather, traffic, airspace restrictions, and service availability. By optimizing flight paths and enabling dynamic separation standards, TBO can increase airspace capacities. This benefit is particularly important for urban and low altitude operations where volume of air traffic is expected to rise significantly.

TBO can facilitate the coexistence of AAM with traditional crewed aviation, military operations, and general aviation, by dynamically managing airspace to accommodate the needs of different users. At density, TBO is enabled by PSU tactical traffic management services. Examples of ongoing research in this area include NASA AMP project and SESAR project SPATIO (U-Space Separation Management); these and emerging efforts aim to deliver Technology Readiness Level 6 or 7 (fully functional prototype) capability before the end-of-the-decade.

TBO systems need to be designed scalable and adaptable, to enable operations that vary greatly in scale (from sUAS to large UAS flying cargo and passenger air taxi services) and operational needs (e.g., varying speeds, altitudes, and mission profiles). The use of flexible routing should enable more efficient flight paths and altitudes. This efficiency is crucial for operational sustainability. TBO will be essential in managing autonomous flight paths, especially in environments where manual intervention may be limited.

Implementing TBO in the context of AAM within the NAS will require collaboration among various stakeholders, including the FAA, AAM service providers, technology developers, and airspace users. It will also involve the development and implementation of new standards and protocols to ensure interoperability, safety, and efficiency in this rapidly evolving domain. The objective of dynamic TBO is to be able to grant a clearance to fly and land at the same time that the aircraft is cleared to take off, in a system that accommodates inherent variations in wind, weather, and unexpected events.

4.5 Artificial Intelligence

Challenges to NAS safety and operational efficiency are growing with increasing user density and diversity. Technological advancements and market-driven forces are creating opportunities for employing Artificial Intelligence (AI) to augment human performance in NAS operations. These opportunities span three key areas: the flight deck, Air Traffic Management/ATC operations, and fleet dispatchers' or remote supervisory station capabilities.

The aviation industry commends the FAA's early initiatives in developing strategies and funding R&D in AI. Notable federal initiatives include:

- FAA Info-Centric NAS[49]
- NASA System Wide Safety Project[50]
- NASA Digital Flight Rules Project[51]
- National Aviation Research Plan – FY 2024-2028[58]
- FAA (AVS) Aviation Safety Research Plan (2024 Draft in review)

Concurrently, the aviation industry is investing broadly in applied AI technology development and implementation. We encourage the FAA to support coordination among federal, industry, academia efforts as a crucial process, setting the stage for the roles of AI in its evolving forms.

Common objectives of these initiatives include:

- Improving internal users' organizational efficiencies for NAS operations, at levels of the own aircraft, own fleets, and total airspace.
- Supporting innovation in aviation products, operations, and services.
- Enhancing human-centric performance in increasingly complex NAS operations.
- Enabling increasing levels of autonomy, including both traditional and new entrant operating capabilities.

[58] https://www.faa.gov/sites/faa.gov/files/FY_2024-2028_National_Aviation_Research_Plan.pdf

AI tools in aviation must be certifiable for their intended purposes across different domains, from advisory roles to safety-of-flight applications. In the case of autonomy of aircraft, industry understands and supports that any AI must be deterministic, trusted, and explainable. Such Applications will likely be built on “closed” foundational models which contain only data qualified for the function, in the interest of these requirements. Industry also commends current FAA exploration of Generative AI tools in support of human decision-making in ranges of NAS operations outside of safety-of-flight or flight-critical uses.

Industry encourages FAA and other government organizational efforts focused on the following outcomes:

- Reliability and robustness: the model must be highly reliable and robust, with minimal risk of failure under varied and unforeseen conditions.
- Transparency and explainability: the model's decisions and predictions must be transparent and explainable to ensure trust and facilitate validation by regulatory bodies.
- Safety and certification standards: the model must comply with existing and future safety and certification standards specific to aviation.

A focused effort by the FAA, other government organizations, academia, and industry is essential for defining and developing AI's role and the means for regulation and regulatory compliance in a roadmap to autonomy.

5. APPENDICES

Abbreviations

5G	Fifth generation
A2X	aircraft to everything (aircraft and infrastructure)
AAM	Advanced Air Mobility
ACAS	Airborne Collision Avoidance System
ACAS-XA	general purpose ACAS system, design version X
ACAS-XO	An extension to ACAS XA designed for particular operations such as closely spaced parallel approaches
ACAS-XR	version of ACAS X intended for rotorcraft/helicopters
ACAS-XU	ACAS for Remotely Piloted Aircraft Systems incorporating horizontal resolution maneuvers.
ADS-B	Automatic Dependent Surveillance Broadcast
AE	Associated Elements
AeroMACS	Aeronautical Mobile Airport Communication System
AFR	Automated Flight Rules
AGL	Above ground level
AI	Artificial Intelligence
AIA	Aerospace Industries Association
AMP	Air Mobility Pathfinders
A-PNT	Alternative positioning, navigation, and timing
ASTM	ASTM, formerly known as American Society for Testing and Materials
ATC	Air traffic control
ATN	Aeronautical Telecommunication Network
ATNS	Automatic Taxi Navigation Systems
ATO	Air Traffic Organization
AURA	Advanced Ultra Reliable Aviation
BVLOS	beyond visual line of sight
C2	command and control
C2CSP	command and control communications service provider
CA	Collision Avoidance
CAAC	Civil Aviation Administration of China
CFR	Code of Federal Regulations
CNS	Communication, Navigation and Surveillance
COA	Certificate of Authorization
CONOPS	Concept of operations
COTS	commercial off the shelf
CPDLC	Controller-Pilot Datalink Communications
CS	control station
CSP	Communications service provider
DAA	Detect and Avoid

D-ATIS	Digital Automatic Terminal Information Service
DCB	Demand-capacity balancing
DFO	Digital Flight Operations
DFR	Digital Flight Rules
DO	Document
DoD	Department of Defense
DOT	Department of Transportation
EASA	European Union Aviation Safety Agency
EB	Engineering Brief
EFB	Electronic Flight Bags
EFVS	Enhanced flight vision systems
EIS	Entry into service
EPIC	Electric Propulsion and Innovation Committee
eVTOL	electric vertical take-off and landing aircraft
FAA	Federal Aviation Administration
FATO	final approach and takeoff area
FCC	Federal Communications Commission
FR	Federal Register
ft	Feet
GA	general aviation
GAMA	General Aviation Manufacturers Association
GBAS	Ground based augmentation system
GBSS	ground based surveillance systems
GE	General Electric
GLS	GBAS Landing System
GPS	global positioning system
ICAO	International Civil Aviation Organization
ICN	Info-Centric NAS
IFP	Instrument flight procedures
IFR	instrument flight rules
ILS	instrument landing system
IPS	Internet Protocol Suite
ITU-R	International Telecommunications Union- Radiocommunication Sector
KBKT	Blackstone Army Airfield
kg	Kilograms
lbs.	Pounds
LOA	Letters of Agreement
LPV	localizer performance with vertical guidance
M:N	M and N represent numbers where M is the number of pilots in control of N number of aircraft
MASPS	Minimum Aviation Systems Performance Standards
Mbps	megabits per second
MHz	Megahertz

ML	machine learning
MOPS	Minimum operational performance standard
MOSAIC	Modernization of Special Airworthiness Certification
MOU	Memorandums of Understanding
ms	milliseconds
MSL	Mean sea level
MTOW	maximum takeoff weight
NAS	national airspace system
NASA	National Aeronautics and Space Administration
NM	nautical miles
NPRM	Notice of Proposed Rulemaking
OAR	Marina Municipal Airport
OEM	original equipment manufacturers
PNT	positioning, navigation and timing
PSR	Primary Surveillance Radar
PSU	Provider of Services for UAM
R&D	Research and development
RAs	resolution advisories
RCP	Required Communication Performance
RF	radio frequency
R-ID	Remote Identification
RLOS	Radio line of sight
RNAV	Area Navigation
RNP	Required Navigation Performance
RPAS	Remotely-piloted aircraft system
RPIC	Remote Pilot in Command
RSP	Required Surveillance Performance
RTC	Return To Course
RTCA	RTCA, formerly known as Radio Technical Commission for Aeronautics
RVSM	Reduced Vertical Separation Minima
RWC	Remain Well Clear
SATCOM	satellite communications
SFAR	Special Federal Aviation Regulation
SESAR	Single European Sky Air Traffic Management
SLA	Service Level Agreement
SPATIO	U-Space Separation Management
SSR	Secondary Surveillance Radar
SUAS	small UAS
SVO	Simplified Vehicle Operations
TBO	Trajectory Based Operations
TCAS	Traffic Collision Avoidance System
TCL	Typical Capabilities List
TERPs	terminal instrument procedures

TET	Transaction Expiration Time
TIS-B	Traffic Information Service Broadcast
TK	helicopter IFR RNAV route
TLOF	Touchdown and liftoff
TR	Technical Report
TSO	Technical Standard Order
UA	Uncrewed aircraft
UAM	Urban Air Mobility
UAS	Uncrewed Aircraft System
UAT	Universal Access Transceiver
UHF	Ultra High Frequency
US	United States
V2V	Vehicle-to-Vehicle
VFR	Visual flight rules
VHF	Very high frequency
VOR	Very high frequency omni-directional range
VOR/DME	Very high frequency omni-directional range / distance measuring equipment
VTOL	vertical take-off and landing
WAAS	wide-area augmentation system (WAAS)
XM	XM brand radio