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Considerations for Airspace Integration Enabling Early Multi-Aircraft (m:N) Operations

Andrew Lacher, Compiler
Langley Research Center, Hampton, Virginia

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National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23681-2199

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Abstract

The aviation community is planning to deploy new aircraft types, with new missions, and advanced operational concepts that are collectively referred to as Advanced Air Mobility (AAM). Many of these new aircraft, missions, and concepts involve remotely piloted aircraft systems, often referred to as uncrewed aircraft systems (UAS). These aircraft are becoming increasingly autonomous and may eventually reach the point where a single or small team of remote pilots (i.e., “m”) could safely operate many airborne aircraft (i.e., “N”) at the same time. These multi-aircraft operations are also known as m:N operations. A government/industry working group on multi-aircraft operations, which was convened by the National Aeronautics and Space Administration (NASA), recognized that a potential barrier to routine m:N operations is the existing need for the remote pilot to routinely interact with a human-centric air traffic control (ATC) system which today mainly occurs via voice communications.

This white paper captures the ideas discussed by a subgroup of subject matter experts on potential mechanisms for routine airspace integration of m:N operations. The working group explored whether it is possible to reduce and/or eliminate the need for ATC services for m:N operations, and thus eliminate the barrier associated with voice communications between the remote pilot and the air navigation service provider (ANSP). The purpose of this white paper is to share concepts and ideas from the airspace integration subgroup. These ideas may contribute to the next step beyond the emerging Beyond Visual Line of Sight (BVLOS) rule being developed by the Federal Aviation Administration (FAA). The group of experts talked about a strategic approach that has three components: 1) VFR-like operations enabled by advanced technologies that met or exceed the safety intent of traditional VFR procedures; 2) ATC Preapproved Terminal Airspace Areas for technology-enabled VFR-like operations; and 3) the ability to transition between m:N operations and operations with a dedicated remote pilot for a single aircraft. In addition, this white paper identifies challenges and areas requiring further study as well as key technical and operational enablers of routine airspace integration of m:N operations.

This white paper does <u>not</u> represent a consensus of the working group members and does <u>not</u> make any specific recommendations. Nor does it represent an official NASA position or recommendation. The subgroup believes that more information, research, technology maturation, and testing is needed before a recommendation can be made on how to safely integrate m:N operations in non-segregated airspace.

Acknowledgements

The compiler of this white paper is not the originator of the concepts and ideas in this paper. They were collected from the discussions and contributions of participants in the NASA Multi-Aircraft Operations (m:N) working group especially the members of the Airspace Integration subgroup who are listed in the Appendix. Many of these subgroup members contributed significantly to the writing of this white paper. The compiler and the subgroup also wish to acknowledge the contributions of several peer reviewers: David Wing (NASA), Ken Goodrich (NASA), Erick Corona (Wisk), and Maxime Gabriel (Joby).

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1. Introduction

This white paper presents thoughts on potential mechanisms for routine airspace integration of multi-aircraft operations (also known as m:N[i] operations) and captures the contributions of a collection of subject matter experts with backgrounds in operations, aircraft capabilities, and research (see Appendix). Over a period of several months, the experts discussed and explored mechanisms that might enable routine m:N operations in non-segregated airspace as part of a National Aeronautics and Space Administration (NASA) working group on multi-aircraft operations. The broad working group recognized that since today most uncrewed flights are operated under Instrument Flight Rules (IFR), a potential barrier to routine m:N operations is the existing need for the remote pilot to routinely interact with a human-centric Air Traffic Control (ATC) system which today mainly occurs via voice communications. The working group explored whether it is possible to reduce and/or eliminate the need for ATC services for m:N operations, and thus eliminate the barrier associated with interaction between the remote pilot and the air navigation service provider (ANSP). An airspace integration subgroup was formed to explore potential mechanisms for consideration following the implementation of the Federal Aviation Administration's (FAA) Beyond Visual Line of Sight (BVLOS) rule. The FAA was expected to release a Notice for Proposed Rulemaking (NPRM) for BVLOS operations in January 2025 [1].

Much of this white paper focuses on reducing the need for separation services provided by an ANSP, the subgroup acknowledges that there are alternative approaches which could be considered and presents in this white paper one alternative which was discussed by the subgroup.

In addition, this paper identifies some challenges requiring further study and key technical and operational enablers of routine airspace integration of m:N operations. The topics addressed should not be considered comprehensive or exhaustive as much more study is required.

1.1. White Paper Purpose

The purpose of this white paper is to share concepts and ideas from a subgroup of subject matter experts with regard to airspace integration of m:N operations that may be a next step beyond the emerging FAA BVLOS rule. This white paper does not represent a consensus of the working group members and it is not intended as a recommendation to regulators. Nor does it represent an official NASA position or recommendation. The subgroup believes that more information, research, technology maturation, and testing is needed before a recommendation can be made on how to safely integrate m:N operations in non-segregated airspace.

1.2. Motivation

The aviation community is planning to deploy new aircraft types, with new missions, and advanced operational concepts that are collectively referred to as Advanced Air Mobility (AAM) [2]. Many of these new aircraft, missions, and concepts involve remotely piloted uncrewed aircraft systems (UAS) that are envisioned to become increasingly autonomous to the point where a single or small team of remote pilots (i.e., "m") could safely operate many airborne aircraft (i.e.,

[i] m:N operations refers to operations where a small number of remote pilots (m) are simultaneously operating a larger number of uncrewed aircraft (N). By its very nature, m:N operations involve uncrewed aircraft.

"N") at the same time. Today, m:N operations are occurring in limited geographical areas after receiving waivers or exemptions from the FAA or other regulators. This usually involves small (sUAS[i]) operating in airspace where encounters with other aircraft are less likely and where ATC services are not routinely provided (i.e., uncontrolled airspace, Class G Airspace). An example is Wing's operations in Dallas as part of FAA's Uncrewed Traffic Management (UTM)/BVLOS operational evaluation activity [3].

The emerging AAM community envisions larger UAS will need to operate in airspace where ATC services are available and potentially a significant number of other aircraft operating. This includes concepts such as Wisk's[ii] Generation 6 electric Vertical Take-off and Landing (eVTOL) aircraft conducting air taxi operations in urban areas (Classes B, C, D, E, and G airspace) [4] and Reliable Robotics operating fixed-wing uncrewed cargo aircraft, operating from existing runways used by traditionally crewed aircraft. There are numerous use cases for m:N operations to include: small UAS (sUAS); large fixed-wing UAS; eVTOLs; and High-Altitude Long Endurance (HALE)[iii]. The UAS community is pursuing approval for m:N operations because they are projected to: 1) reduce operational costs which in turn increases public access to air mobility; and 2) enable business and operational scalability.

The subgroup defines m:N operations as:

> *Multi-aircraft Operations or m:N Operations: One or more remote pilots or equivalent individual(s) are supervising, responsible, and accountable for two or more aircraft in the air at the same time enabled by high-levels of automation controlling the safe intended trajectory of the aircraft and which has authority to perform much of the flight operations including decision-making for the safety of flight*

Except for sUAS operating at very low altitudes (e.g., below 400 feet above ground level)[iv], for the most part remotely piloted UAS operate today under IFR which involves them maintaining direct voice communications with ATC, complying with ATC clearances, and following controller instructions. Given that there is no pilot on board the aircraft to see and avoid other aircraft, operating IFR adds another layer of safety on top of any detect and avoid mitigations because ATC is providing separation assurance. This is part of a layered approach to safety.

In today's Air Traffic Management (ATM) system, there is heavy reliance upon voice communications for ATC services with timely communications and compliance with instructions expected. This requirement could be a potential obstacle for m:N operations using the IFR operating mode and raises the following questions:

- Could ATC interaction be a limiting factor in the number of aircraft a single remote pilot could simultaneously manage?

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[i] The FAA defines a small UAS as an uncrewed "aircraft weighing less than 55 pounds on takeoff, including everything that is on board or otherwise attached to the aircraft". See Title 14 of the Code for Federal Regulations section 1.1.

[ii] Wisk is a subsidiary of The Boeing Company.

[iii] These are also sometimes referred to as High Altitude Platform Stations or Systems (HAPS).

[iv] Aircraft operating in visual line of sight (VLOS) of the remote pilot operating as described in 14 CFR Part 107 [5]. There are some BVLOS operations that have been approved via certificates of authorization (COA) and/or waivers.

- Will the remote pilot be able to maintain the necessary situation awareness to safely monitor multiple aircraft and interact with multiple controllers on different radio frequencies at the same time, including switching their attention between aircraft as needed?
- Will the remote pilot be able to manage the cognitive effort and maintain the necessary focus?
- Is there a potential for the remote pilot to confuse aircraft or controllers as they respond to revised clearances and/or ATC instructions?
- Will latency in communications, the need to potentially repeat communications, and delays in remote pilot response/action have a cascading effect on traffic efficiencies (i.e., place constraints on ATC ability to be responsive, potentially requiring increased spacing buffers) resulting in reduced capacity?

These questions led the subgroup to discuss operational mechanisms that don't involve receiving ATC separation services, as if the UAS is operating under visual flight rules (VFR). The subgroup postulated whether a highly automated flight operations could function using advanced technology solutions equivalent to the airspace operational risks of VFR operations. In general, the subgroup felt that relatively mature technologies (which are more advanced than technologies currently being used in aviation) and techniques under development could potentially enable uncrewed aircraft to be able to comply with the safety intent of VFR procedures [6]. This would be an alternative means of compliance in airspace where VFR operations occur today (e.g., Class E airspace). In other words, could advanced technology enable operators (i.e., remote pilots) to manage conflicts and remain well clear from other aircraft comparable to an on-board pilot following VFR procedures? The subgroup coined the term "Technology-Enabled Operations" to refer to an operating mode that is procedurally equivalent to VFR but leverages advanced technologies (e.g., automated conflict resolution, sharing of operational intent, non-cooperative sensors) over the pilot vision and other technologies (e.g., cockpit display of traffic) routinely used by VFR pilots today.

The subgroup acknowledges that this mechanism would only be feasible if this advanced technology could be proven to be capable of compliance with the safety intent of VFR procedures and that these technologies will be acceptable to regulators. The subgroup was fairly confident that the aviation community is on a path towards developing the necessary technologies and gaining acceptance by the FAA since they are roughly the same technologies and techniques that would be required to enable compliance with the operating mode associated with the emerging BVLOS rule. While the BVLOS rule would only be applicable to certain aircraft (e.g., <1320 lbs) and limited to certain airspace where encounters between traditional manned aircraft and UAS are less likely, the technology maturation to technology-enabled VFR-like operations of larger aircraft in integrated airspace seemed plausible to the subgroup.

The rest of this white paper assumes the following to be viable in the decade which follows the BVLOS rulemaking:

- The necessary technological capabilities and enablers would exist and be able to be assured as being safe to the acceptance of aviation regulations.

- m:N operations using the VFR-like technology-enabled operational approach would be demonstrated to be interoperable with existing piloted and remotely piloted operations.
- Technology-Enabled Operations would be applicable and available to Part 91 and Part 135 operators.
- Initially, VFR-like Technology-Enabled Operations would be first authorized in airspace where VFR operations routinely occur today (e.g., Class E airspace, below FL180 or above FL600) and may be explicitly permitted by ATC in other airspaces (see Section 4).

The term 'pilot' and 'pilot-in-command' are used in this paper to describe the human who has the command-and-control authority over flight operations of the uncrewed aircraft even though it may be remote. Depending upon the specific design of the aircraft and its ground control system, this human pilot may not be able to exert inner-loop control[i] over the aircraft remotely. They would be able to influence the aircraft's flight path through high-level guidance and supervision. It is not assumed that this individual would necessarily have the same qualifications, experience, training, and licensing requirements of today's pilots. It is assumed that they would have qualifications, experience, training, and licensing requirements commensurate with their duties to ensure safe flight operation.

1.3. Scope

While many operational and technical challenges are associated with the routine operation of remotely piloted UAS in integrated airspace, these topics are not within the scope of this paper. The subgroup discussions and this paper focus on the unique challenges associated specifically with m:N UAS operations in integrated airspace.

This white paper examines ideas and concepts regarding m:N operations beyond what would be enabled by the soon to be released FAA rule that is expected to authorize BVLOS operations enabled by technology for certain aircraft in limited airspace. The ideas and concepts in this white paper focus on an operating mode which is enabled by advanced technologies that could apply to broader numbers of aircraft in integrated airspace that eliminates the need for m:N operations to use ATC separation services. The white paper presents ideas for expanding the airspace where routine m:N operations might be feasible and how such operations could enable flights into and out of terminal airspace.

Recognizing that concept of VFR-like Technology-Enabled Operations is not the only feasible approach to airspace integration of m:N operations, an alternative idea is presented in Section 6. It is beyond the scope of this paper to consider all alternatives and to analyze the relative trade-offs among alternatives.

2. Strategic Approach

Recognizing the potential constraint of human-centric ATC and ATC voice communications on the ability to shift towards widespread m:N operations, the subgroup discussed approaches towards minimizing routine interactions with ATC. The subgroup considered alternatives to IFR

[i] Inner loop controls the flight surfaces, including the ailerons, elevators, and rudder to stabilize the aircraft.

operations for m:N operations which, in addition to 14 CFR Part 107 operations [5], is the primary mechanism for authorizing most uncrewed operations in the National Airspace System (NAS).

The subgroup formulated a strategic approach with three specific components which are elaborated upon in Sections 3, 4, and 5, respectively. The three components are as follows:

- **VFR-like Technology-Enabled Operations** would be roughly equivalent to VFR procedures enabled by advanced technologies. It is envisioned that this operating mode would need to be shown to meet or exceed the safety intent of the procedures associated with today's VFR operations. These operations would differ from VFR operations in that they would not rely upon an on-board pilot to "see and avoid" hazards or navigate with visual reference to the ground. Instead, advanced technology would enable an alternative means of compliance that achieves an equivalent or greater level of performance and mitigation of operational risks. Thus, these operations may be feasible in both visual meteorological conditions (VMC) as well as potentially instrument meteorological conditions (IMC). These operations are envisioned to occur in airspace that routinely has enroute VFR operations today (e.g., Class E).
- **ATC Preapproved Terminal Airspace Areas for Technology-Enabled Operations.** The subgroup discussed that ATC may designated pieces of Class B, C, or D airspace that ATC subject matter experts have determined could accommodate Technology-Enabled Operations without requiring ATC communications. This is somewhat analogous to how the FAA has designated altitudes from the surface in Class B, C, and D airspace where sUAS under 14 CFR Part 107 with prior authorization and notification could operate as if the airspace was effectively Class G airspace.[i] The FAA, in collaboration with industry, developed the Low Altitude Authorization and Notification Capability (LAANC) [7] to facilitate such operations. A similar capability could be established to enable coordination of the usage of ATC Preapproved Terminal Airspace Areas for Technology-Enabled Operations. The process of ATC designating altitudes and the use of LAANC for authorization and notification of Part 107 operations is cited as an example of precedent.
- **Transition between m:N Operations and Operations with a Dedicated Remote Pilot.** The subgroup discussed how the entire flight does not necessarily need to be conducted under m:N control using a VFR-like, technology-enabled operating mode. The subgroup envisioned that in some complex areas, the flight may have to transition between m:N/Technology-Enabled Operations to remotely piloted 1:1/IFR operations as required for a safe, orderly flow of air traffic.

The subgroup felt that enabling technologies (which are discussed in more detail in section 8) are likely to be mature enough for operational use in the next few years. In general, the subgroup discussed that the concepts contained in this paper are potential next steps to consider after BVLOS operations are enabled under the forthcoming NPRM. In many ways, these concepts would be dependent upon technology capabilities for BVLOS operations, once approved by regulators, which would be normalized through low altitude UAS operations and therefore gain

[i] This is commonly referred to as UAS Facility Maps by the FAA. See: https://www.faa.gov/uas/commercial_operators/uas_facility_maps

acceptance for eventual use in integrated airspace. The FAA's BVLOS NPRM is expected to establish a regulatory process for routine BVLOS operations of certain UAS (up to 1,320 pounds) with new operating rules that define a pathway for regulatory approval of third-party services that include UAS Traffic Management (UTM) service suppliers [1]. The subgroup believes that the forthcoming BVLOS NPRM will:

- Create a path toward routine m:N operations for limited UAS operations
- Be constrained to airspace and operations not receiving ATC services
- Be dependent upon technology capabilities (both in the air and on the ground) that would ensure aircraft remain separated from hazards including other BVLOS UAS and traditionally crewed aircraft operating in the vicinity
- Establish a residual risk level acceptable to the regulator
- Enable BVLOS operations of UAS where encounters with traditionally crewed aircraft are likely to be minimal due the nature of the airspace in which the operations are occurring
- Potentially involve changes to right-of-way rules
- Be dependent upon strategic mitigations/procedures to help reduce the risk of encounters with other aircraft

While much of the subgroup discussions were spent on the potential for Technology-Enabled Operations, ATC Preapproved Terminal Airspace Areas, and the ability to transition between m:N and 1:1 operations, the subgroup acknowledged that there are alternative approaches that could potentially address some of issues described in section 1.2. One such alternative explored in some detail was that m:N operations could be conducted in a manner that aligns a remote pilot with a corresponding controller such that a single remote pilot is responsible for multiple aircraft in a single air traffic sector. Thus, a single remote pilot would monitor a single ATC frequency. As any of the aircraft transition sectors, the remote pilot would hand-off responsibility to another remote pilot, similar to how controllers hand off responsibility between sectors in an ATC facility today. This alternative approach is discussed in Section 6.

3. Technology-Enabled Operations that Follow VFR Equivalent Procedures

As discussed by the subgroup, Technology-Enabled m:N Operations could be understood as aircraft operations that satisfy the safety intent of, and are behaviorally equivalent to, VFR operations, but do not rely on human vision or ATC services for the avoidance of hazards including other traffic. The use of onboard and/or offboard technology for these functions allows both for remote piloting and increased automation. Currently, in certain classes of airspace (e.g., Class E), VFR flights operate independent of ATC. The subgroup envisioned that Technology-Enabled Operations would occur in the same airspace classes where VFR operations can be conducted today. Further, by eliminating reliance on human vision, m:N operations using technology-enabled behaviors that are equivalent to VFR may be able to continue into Instrument Meteorological Conditions (IMC) without the need to transition to IFR, and thus continue to remain independent of ATC.

The idea of VFR-like Technology-Enabled Operations is consistent with the long-running history of aviation advancements driven by authorized use of new technologies as they emerge and could be demonstrated as safe and reliable to be used within an acceptable level of risk. Technology has been advancing the aviation industry since its inception, propelling it forward to new types of operations, missions, and aircraft types. However, the fundamental operating modes of VFR and IFR, which evolved decades ago, remain relatively unchanged and constrain full exploitation of the capabilities of higher levels of technology, integration, and automation. This limitation has been identified for quite some time with conceptual solutions being proposed in many publications over the years [8,9,10,11,12]. Oftentimes, the proposed operating concepts include new operating modes together with new flight rules that increase reliance on technological capabilities available to modern crewed and uncrewed aircraft. Examples include Augmented VFR [13], Electronic Flight Rules [14], Digital Flight and Digital Flight Rules [15], Autonomous Flight Rules [16], U-Space Flight Rules [17], etc. Once considered unimaginable by some in the aviation community, the emergence of new operating modes like Part 107 [5] and the anticipated BVLOS rule [1] indicate that considering such solutions are likely to be more acceptable in the very near future.

3.1. Visual Flight Rules Today

VFR operations accommodate aircraft with minimal equipment on board and allow for human vision and decision-making to be used for navigation (by visual reference to ground features), for aircraft attitude control (by visual reference to the horizon), and for avoidance of hazards including terrain, obstacles and other traffic. Currently, VFR operations are constrained to specific visibility requirements, weather minimums, and cloud clearance [18]. VFR is the most basic way to fly based upon pilot rating/experience and aircraft equipment requirements. By contrast, the operations described in this paper are highly technology reliant and may require special training and operational limitations at the outset.

Without human vision from the cockpit available, navigation and avoidance of traffic, terrain and obstacles would need to be fulfilled in other ways (e.g., access to aeronautical and terrain databases, live data updates, etc.). m:N operations leverage advanced automation to shift the human's role from continuous control to providing oversight, guidance, and supervision. Technology-Enabled Operations could likewise be performed with human oversight instead of continuous human control, this becomes a key enabler for m:N operations.

3.2. Technology Enablers

The subgroup focused on the premise that modern technologies would provide an equivalent means for navigation and avoidance of hazards that satisfies the safety intent of VFR operational procedures without ATC services. It is expected that Technology-Enabled Operations would behave similarly to traditional VFR operations but leverage algorithms and other information technologies vs. having a human pilot on board the aircraft observing the environment and making judgment calls to avoid hazards. This would eliminate the need for direct human manipulation of flight controls with the human pilot instead providing overall guidance to manage UAS operations. Technology-Enabled Operations would use sensors, digital information, and automation to achieve an equivalent or greater level of safety when compared to traditional VFR operations.

The subgroup discussed how the following readily available and rapidly maturing technologies could be used to enable operations that are behaviorally equivalent to VFR operations:

- **Area Navigation**: Modern means for reliable electronic area navigation (RNAV)
- **Real-time Information Services and Data:** Access to real-time authoritative databases and information services regarding non-traffic hazards (e.g., terrain, obstacles, weather) either on board or available via a data link to off-board sources
- **Strategic Conflict Management:** Automated mechanisms to strategically deconflict operations including capabilities like UTM
- **Tactical Conflict Management and Collision Avoidance:** Detect and Avoid (DAA) systems for all traffic including those that participate in cooperative surveillance (e.g., Automatic Dependent Surveillance – Broadcast, ADS-B) and those that do not

3.2.1. Area Navigation

Current navigation solutions may be able to fulfill the necessary navigation precision for most flight phases. Global Navigation Satellite Systems (GNSS), with Space-Based Augmentation Systems (SBAS) now provide nearly global coverage for precision navigation for crewed and uncrewed aircraft operations. Although suitable for most phases of flight, from departure to approach, these alone do not yet provide assured accuracy, integrity, and availability sufficient for automatic takeoff and landing. Other existing and novel technologies, such as machine vision, ground-based augmentation electronic navigation, and other sensors coupled with inertial navigation systems, are being considered as possible solutions to enhance GNSS/SBAS and provide resilience when GNSS is unavailable [19].

3.2.2. Real-time Information Services and Data

The subgroup discussed how access to certain information services and data would likely be required for Technology-Enabled Operations. Aircraft used for such operations would be highly advanced and able to function without direct human control but under continuous human oversight. Access to onboard and/or offboard data and along with regular updates would be essential for assurance of the continuous safe flight and landing. In other words, the aircraft, just like any pilot, would need to have access to current information pertinent to the flight and flight execution in order to fulfill aeronautical decision-making piece of the puzzle. These databases include aeronautical information (e.g., Notices to Airman (NOTAMs), aeronautical charts, aerodromes data) and terrain data (e.g., obstacle clearance, terrain clearance). Additional services that could be included under this enabler would provide current and forecast weather along the route. While weather detection capability may exist onboard some aircraft, most aircraft would need external monitoring for weather conditions to enable the continuity of operations and compliance with applicable weather minimums.

3.2.3. Strategic Conflict Management

“Conflict management will limit, to an acceptable level, the risk of collision between aircraft and hazards” [20] including other traffic. The International Civil Aviation Organization (ICAO) defined three layers of conflict management in their Global Air Traffic Management Operational Concept (GATMOC):

- **Strategic Conflict Management:** Reduces the need for separation provision to a designated level. Strategic conflict management includes airspace organization and management, demand and capacity balancing, and traffic synchronization [20].
- **Separation Provision or Tactical Conflict Management:** Is the tactical process of keeping aircraft away from hazards by at least the appropriate separation minima. Typically, the separation provision will only be used when strategic conflict management cannot be used efficiently. In general, the predetermined separator[i] will be the airspace user, unless safety or ATM system design requires a separation provision service (i.e., ATC separation services) [20].
- **Collision Avoidance:** Activates when the "separation mode has been compromised" to ensure a collision with a hazard is avoided [20].

Strategic deconfliction can be thought of the process that ensure that the rate of tactical conflicts that would require resolution can be addressed with the processes and technologies for tactical conflict management. Tactical conflict management can be thought of as the process that identifies and resolves tactical conflicts.

Strategic deconfliction through third-party services would help ensure that flights are planned away from known hazards and airspace constraints and also ensure that tactical maneuvers could enable aircraft to remain well-clear of each other. The subgroup felt that strategic deconfliction could be a significant safety enabler for m:N operations, reducing the need for tactical deconfliction and flightpath changes. For scheduled operations that operate from the same aerodromes, strategic deconfliction may look at arrival and departure aerodrome (e.g., vertiport) slots that are dynamic in nature and could be adjusted based on the aerodrome "operating picture". Estimated at-fix arrival times or required time of arrival could be used to ensure efficiency within the network. These measures are especially useful for inter-operator coordination, which would likely be required as the tempo of operations increases, specifically at aerodromes in high demand. Part of strategic deconfliction could also be pre-established practices that these operators use within the network of their operations. For aircraft that operate in and out of standard aerodromes, strategic deconfliction could be performed with known flight intents (i.e., IFR flight plans and conformance monitoring functions). As more flights become fully automated, the sharing and real-time updating of 4D flight trajectories through service providers would allow strategic deconfliction (based on flight intent) to occur throughout a flight and to close the time-horizon gap between strategic and tactical deconfliction. This, however, does not include interactions with VFR aircraft that, in the majority of cases, do not have a submitted or known intent. With that in mind, strategic deconfliction would need to be supplemented with tactical deconfliction based on traffic detected in the vicinity of the uncrewed aircraft.

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[i] It is essential that there is no ambiguity as to who is responsible for keeping an aircraft separated from hazards. This decision agent will be called the predetermined separator. The predetermined separator must be defined for all hazards; however, different predetermined separators may be defined for different hazards. For example, in some cases, the airspace user may be the predetermined separator in respect to weather and terrain, and the separation service provider (i.e., ATC) will be the predetermined separator in respect of other hazards [20].

3.2.4. Tactical Conflict Management and Collision Avoidance

As with traditional VFR operations, with the concept of Technology-Enabled Operations, the operator (i.e., the remote pilot) would be the designated separator for all conflicts with hazards including other traffic like traditional VFR, other technology-enabled, and IFR operations. This is often referred to as "self-separation[i]". As Technology-Enabled Operations are highly dependent upon advanced technology to enabled behaviors that are equivalent to VFR there is an opportunity for the conflict horizon to be extended beyond that of traditional VFR. This is because the conflict horizon is no longer limited by human vision. The use of cooperative surveillance (often referred to as electronic conspicuity) and the sharing of operational intent and other ground-based information enables conflicts to be accurately identified using trajectories that extend tens of minutes into the future and potentially include planned maneuvers. As the ICAO GATMOC indicates, the "conflict horizon will be extended as far as procedures and information will permit" [20].

DAA systems would be essential to conduct VFR-like Technology-Enabled Operations. The subgroup discussed that DAA systems would both help ensure aircraft remain well-clear of other aircraft and if necessary, avoid collisions. Emerging DAA systems are expected to offer comprehensive solutions through heterogeneous sensor fusion and automated assessment of potential conflicts and generation of conflict-free maneuvers. These may be used to avoid other traffic and would likely include capabilities to identify and avoid obstacles and terrain. It has been noted that ground- and aircraft-based cooperative and non-cooperative traffic surveillance would significantly improve the traffic awareness of m:N operations in the sense that the system would become more proactive and less reactive. The multi-aircraft flight operators would be responsible and accountable for flight safety ensuring that the aircraft could promptly identify potential hazards and have sufficient time to respond to avoid these hazards without direct human involvement.

The subgroup discussed the need for tactical deconfliction and DAA concepts to be layered, with technology meeting the appropriate levels of performance to allow residual risk acceptance. This specifically is relevant to the critical phases of flight during approach and departure, as there is a capability gap for some onboard DAA solutions during those flight phases due to ground clutter making traffic detection challenging. Additional means of surveillance, including ground-based solutions may be necessary to fill that gap in order to support continuous safe flight.

3.2.5. No Need for Cloud Detection

When comparing Technology-Enabled Operations to traditional VFR, visibility limitations (i.e., fog, clouds, etc.) are an important consideration. Poor visibility conditions limit a pilot's ability to see and avoid, navigate with reference to the ground, etc. Hence, VFR operations are limited by visibility conditions, as the pilot must maintain a set lateral and vertical distances (i.e., clearance) from clouds to see and avoid IFR traffic emerging from clouds. Unlike VFR, IFR operations are not limited by visibility (except near takeoff and landing), as ATC provides separation services to all traffic operating in IMC, and IFR routes and procedures provide known obstacle-free flight paths. IFR aircraft are generally provided three or five nautical miles (NM) separation from other

[i] Self-separation is the situation where the airspace user is the separator for its activity in respect of one or more hazards [20].

IFR aircraft, largely due to the historical and technical capabilities of the systems used by ATC to monitor traffic and provide separation services. This traffic separation requirement could constrain or prevent medium to high density m:N operations. Technology-Enabled Operations do not rely on human vision to see and avoid hazards and instead use information, technology, and automation to detect aircraft, maintain awareness of terrain and obstacles, determine navigational position, and determine the appropriate flight path. The subgroup discussed how visibility conditions and cloud clearance requirements may not limit Technology-Enabled Operations and may not preclude them from entering clouds, fog, or other conditions that limit visibility. If future Technology-Enabled Operations are permitted in IMC, then it would avoid the need to equip the aircraft with systems specifically to detect and avoid clouds. NOTE: Depending upon the DAA sensor technology applied, there may be operational and environmental limitations to ensure their required performance.

3.3. Discussion

This section contains topics that were discussed by subgroup related to the topic of Technology-Enabled Operations.

3.3.1. Separation Standards

In today's air traffic management system, separation services are provided by ANSPs like the FAA in the United States. Maintaining specific separation minima ensures that the displacement between aircraft and hazards maintains the risk of collision at an acceptable level of safety.[20] Separation minima are formally defined and sometimes referred to as separation standards and specify the minimum longitudinal, lateral, or vertical distances by which aircraft are spaced through the application of ATC procedures or instructions. ATC ensures aircraft separation vertically by assigning different altitudes; longitudinally by providing an interval expressed in time or distance between aircraft on the same, converging, or crossing courses; and laterally by assigning different flight paths.[21]

Separation standards are formally defined among aircraft receiving ATC services, i.e., between two IFR aircraft and between IFR and VFR aircraft. However, there is no quantifiable standard for separation among VFR aircraft. For DAA systems that could measure the distance between aircraft using various technologies, progress has been made to formally define (i.e., quantify) standards for separation between UAS and other traffic. RTCA DO-365C, the Minimum Operational Performance Standards for DAA systems, defines DAA Well Clear (DWC) as a temporal-spatial boundary between aircraft, which is in effect a self-separation standard for UAS. Different parameter values that define the size of the boundary are used for DWC for enroute and terminal areas, and a smaller boundary has been proposed for urban routes to safely accommodate increased traffic density there. There are also different DWC standards for traffic with different equipage. For enroute traffic with a transponder or which broadcast their position (i.e., cooperative traffic, which includes all IFR traffic) the horizontal separation minimum is 4,000 ft with a time parameter (tau) of 35 seconds. For traffic not detected with a transponder signal (i.e., non-cooperative, often operating VFR) the horizontal separation minimum is reduced to 2,200 ft with no tau factor. The vertical separation minimum for all traffic is 450 ft. Therefore, DAA technology and the framework of DWC separation standards provides a means for self-separation in both VMC and IMC [22].

Without intent information, conflict identification is dependent upon current position and velocity (essentially a vector). Through the sharing of operational intent, conflict identification can be trajectory based. The impact on separation minima will require additional research.

As the subgroup discussed, one of the premises for Technology-Enabled Operations is that such operations should have little to no impact on existing flight operations in the airspace. From the perspective of IFR or VFR aircraft in VMC, an aircraft operating as a Technology-Enabled Operation would behave the same as any other VFR aircraft encountered, being able to self-separate following right-of-way rules. With that in mind, VFR-like Technology-Enabled Operations flying above 3,000 ft AGL would use prescribed VFR altitudes - ordinal altitudes appropriate for the direction of flight plus 500 ft. This behavior follows existing deconfliction practices and provides operational predictability in the airspace.

3.3.2. Potential Perspective of ATC

In the subgroup's thinking, the perspective of ATC may be that Technology-Enabled Operations could behave and look similar to traditional VFR. All aircraft (including Technology-Enabled Operations) entering cooperative surveillance airspace (e.g., Mode C Veil[i]) would be equipped with a transponder and ADS-B, to be visible to ATC beyond the coverage of primary radar and be identifiable as non-IFR traffic (akin to VFR squawk 1200). One notable difference would be the presence of Technology-Enabled Operations in IMC. The subgroup discussed how controllers are not necessarily aware of the specific meteorological conditions of the airspace under their control, but they are generally aware of the forecast weather and the presence of cloud layers and may not be expecting VFR or VFR-like aircraft at certain altitudes or in the vicinity of known weather. Consequently, it may be helpful for the ANSP to specify a unique transponder code for Technology-Enabled Operations, distinguishing them from traditional VFR aircraft, so that this behavior does not cause concern or prompt controller action.

The subgroup discussed that for Technology-Enabled Operations in IMC, ATC's responsibilities would remain the same as for traditional VFR traffic in VMC, namely to provide traffic information to IFR traffic and to expect the Technology-Enabled Operations to self-separate [23]. Note the subgroup did not consider this the same as delegated separation [24]. However, ATC providing traffic information to the pilot of an IFR flight in IMC could cause confusion, as the IFR pilot would be unable to visually locate the aircraft operating as a Technology-Enabled Operations. If the controller could identify the aircraft as Technology-Enabled Operations (by squawk code), then the traffic information call may be modified, or the response to the pilot's reply could include further information, such as informing the pilot that the traffic is equipped to operate and self-separate in

[i] Mode C Veil. The airspace within 30 nautical miles of an airport listed in Appendix D, Section 1 of 14 CFR Part 91 (generally primary airports within Class B airspace areas), from the surface upward to 10,000 feet MSL. Unless otherwise authorized by ATC, aircraft operating within this airspace must be equipped with an operable radar beacon transponder with automatic altitude reporting capability and operable ADS-B Out equipment. However, aircraft that were not originally certificated with an engine-driven electrical system or that have not subsequently been certified with a system installed may conduct operations within a Mode C veil provided the aircraft remains outside Class A, B or C airspace; and below the altitude of the ceiling of a Class B or Class C airspace area designated for an airport or 10,000 feet MSL, whichever is lower [21].

IMC. The subgroup considered the fact that due to this novel situation, two-way radio communications with ATC for the Technology-Enabled Operations may be a minimum requirement for entering IMC.

The subgroup recognizes that these and other issues would require further study which is highlighted in the box below. Other similar highlight boxes are used throughout the document to call attention to other areas requiring further study.

Areas Requiring Further Study

- How will sharing of operational intent information impact separation minima?
- Could it be problematic for a controller if a Technology-Enabled Operation is not readily distinguishable from a traditional VFR aircraft?
- Will controller expectations of behavior be different between VFR-like Technology-Enabled Operations and traditional VFR?
- Would there be value in considering a new transponder code for Technology-Enabled Operations so controllers are aware (e.g., 1201 or 1300)?
- What challenges are created by existing regulatory barriers which prohibit unmanned aircraft from using ADS-B unless under a flight plan and talking with ATC (i.e., IFR)? – 14 CFR §91.225(h)
- Will Technology-Enabled Operations in IMC need any specific additional capabilities with regard to interaction with ATC?
- Will there be added collision risk for a Technology-Enabled Operations in IMC given that the IFR pilot has not means to visually remain well clear of the traffic?
- Should Technology-Enabled Operations at least initially be restricted to just VMC?

3.3.3. Evolutionary Path

The subgroup discussed that without any changes to Title 14 of the Code of Federal Regulations that modify the requirements for VFR operations or introduces a new operating mode along the lines of some of the new flight rule concepts, waivers and exemptions would be required to perform VFR-Like Technology-Enabled Operations without on-board human vision. The technology associated with operations that would be enabled by the BVLOS rule currently under consideration at the FAA would set a likely precedent for the future acceptability of this technology as an enabler of Technology-Enabled Operations. The FAA has already established procedures to process waivers to 14 CFR 91.113 right-of-way rules in order to allow alternatives to “see and avoid” for BVLOS operations. However, even with a waiver to §91.113, current UAS operations in controlled airspace are assumed to be IFR. Additional waivers would be required for the other vision-based functions assumed for VFR. Due to the novelty of the Technology-Enabled Operations concept, and uncertainties associated with implementation in a real-world environment, introduction of these operations needs to be gradual in order to carefully assess the requirements and impact on the existing stakeholders. For example, initial flight trials and operations may be limited to VMC and/or use IFR procedures for certain phases of flight. Some m:N operations would also require special instrument flight procedures designed to replace procedural segments requiring visual confirmation (i.e., conducting approach and departure with visual segments), which would be added to the U.S. Standard for Terminal Instrument Procedures (TERPS).

To ensure gradual implementation, Technology-Enabled Operations could initially be deployed at a low tempo in specific areas to gain operational maturity that would then allow expansion to m:N operations beyond those areas and reach medium to high tempos. An example of such implementation could be deployment within Mode C Veil areas where most aircraft have to be ADS-B equipped. Doing so would minimize the challenges with integration in environments with non-cooperative aircraft.

Areas Requiring Further Study

- Would there be value in making the class of airspace where BVLOS operations are allowed under Part 108 a waiverable regulation?
- Would it be possible to enable Technology-Enabled Operations initially through waivers/exemptions and special procedures so that these operations could be permitted in limited areas with specific operational limits?
- Would starting Technology-Enabled Operations initially in the Mode C veil reduce challenges associated with non-cooperative aircraft?

4. ATC Preapproved Terminal Airspace Areas for Technology-Enabled Operations

The subgroup discussed a complimentary concept to Technology-Enabled Operations which could expand the area where these VFR-like operations could be allowed. This concept involves the ANSP designating preapproved airspace areas within controlled terminal airspace (i.e., Class B, C, and/or D) where VFR-like Technology-Enabled Operations could occur with minimal routine ATC interaction. This section explores the concept of ATC Preapproved Terminal Airspace Areas, their potential implementation, and uses the precedent set by ATC designating altitudes in terminal areas where Part 107 operations can be approved with authorization and notification.

4.1. Utilizing Lightly Used Areas in Classes B, C, and D Airspace

Controlled airspace Class B, C, and D are designed to protect the departure and approach paths, surrounding towered airports. However, these airspace classes are not uniformly utilized; there are portions that are underused or not routinely used by aircraft receiving ATC separation services. These areas are often included in the broader airspace classification due to charting conventions and administrative boundaries rather than operational necessity.

The subgroup discussed that identifying and designating these underutilized segments of airspace as ATC Preapproved Terminal Airspace Areas for Technology-Enabled Operations could enhance airspace efficiency by enabling underused airspace to accommodate new traffic growth including m:N operations.

4.2. Premise and Implementation Strategy

Through discussions of the subgroup, a fundamental premise that emerged was to make specific portions of controlled airspace (i.e., Classes B, C, and D airspace), that would otherwise require VFR aircraft to be in communications with and/or received clearance from ATC available for Technology-Enabled Operations through an automated notification and approval system. As discussed by the subgroup, key elements of this strategy include the following assumptions for the new ATC Preapproved Terminal Airspace Areas:

1) ***Class E-like Operations:*** These designated areas would effectively operate like Class E airspace for authorized users, allowing for VFR-like Technology-Enabled Operations without changing the official airspace classification.

2) ***Non-Exclusive Use:*** The airspace would remain open to other aircraft operating under existing regulations. Technology-Enabled Operations must integrate seamlessly without impeding other airspace users.

3) ***No ATC Separation Services:*** ATC would not provide separation services to Technology-Enabled Operations which are behaving in a manner equivalent to VFR. Remote pilots would utilize authorized technologies for self-separation.

4) ***Automated Authorization Process:*** Remote pilots would notify ATC of their intent to use the airspace through an automated system, which, subject to ATC defined constraints, would then grant authorization. Such a system would also provide ATC with situational awareness of potential operations in this airspace. This process mirrors the LAANC model, facilitating efficient and timely approvals.

5) ***Dynamic Airspace Management:*** ATC would retain the ability to manage the status of these preapproved areas in response to changing operational circumstances. For instance, if increased traffic or special activities were occurring that precluded VFR-like Technology-Enabled Operations, ATC could halt new authorizations or rescind existing ones for flights not yet in the airspace.

6) ***Minimal Communication Requirements:*** After receiving authorization, remote pilots would not be required to maintain routine communication with ATC regarding operations in the preapproved areas, reducing controller workload and communication channel congestion. Remote pilots would have to be on a frequency reachable by ATC for non-routine communications.

7) ***Standard Equipment Requirements:*** No additional equipment would be mandated beyond what is necessary to meet the authorization criteria, including technologies for navigation and detect-and-avoid capabilities. This ensures accessibility for remote pilots without imposing additional burdens.

This approach allows for more efficient use of airspace by accommodating advanced operations in controlled environments while maintaining safety and minimizing the impact on the ATC workload.

4.3. Parallels with LAANC and the Incorporation of Automation

The process of ATC designating altitudes in terminal airspace and the use of LAANC for authorization and notification of Part 107 operations is cited as an example of precedent for integrating unmanned aircraft operations into controlled airspace through automation and collaborative airspace management. LAANC is an automated system developed by the FAA to facilitate real-time processing of airspace authorizations below 400 feet in controlled airspace under Part 107 regulations. It streamlines the process of gaining access to Class B, C, D, and E surface areas by automating the authorization and notification procedures, thereby reducing the workload on ATC and enhancing operational efficiency. Each facility defined airspace (surface to a specific altitude with a max of 400' AGL) that shows the maximum altitudes around airports where the FAA may authorize, through LAANC, Part 107 UAS operations without additional safety analysis. See Figure 1 for an example.

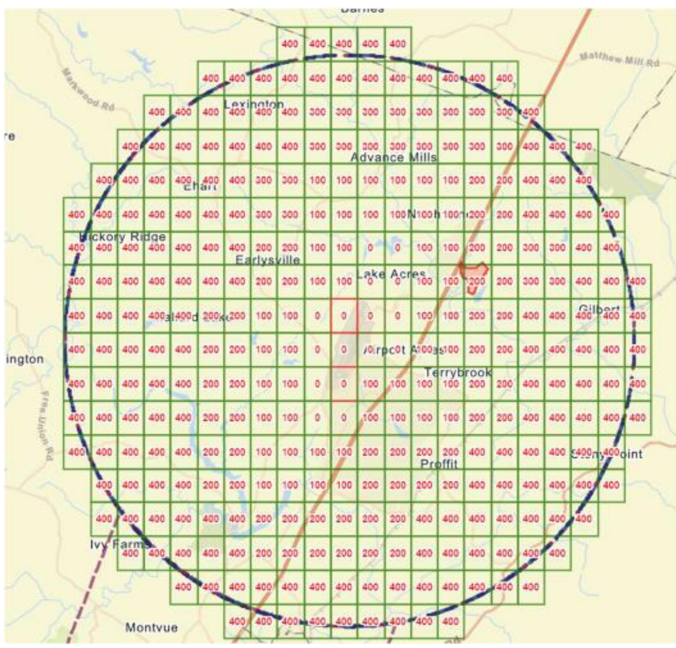

Figure 1. Example of UAS Facility Maps – Charlottesville, VA (CHO) – Predesignated Airspace where UAS Operations are Permitted via Authorization under LAANC [25]

4.3.1. Functionality and Automation in LAANC

LAANC automates the interaction between drone remote pilots and ATC by the following:

1) **Automated Authorization Requests:** Remote pilots submit flight plans through approved UAS Service Suppliers, which are then automatically processed against facility-defined parameters and airspace data.

2) **Facility Maps and Altitude Ceilings:** Each ATC facility provides detailed facility maps indicating the maximum altitudes for unmanned operations in different grid squares, reflecting local operational patterns and safety considerations.

3) **Real-Time Data Exchange:** The system facilitates instantaneous data exchange between remote pilots and ATC, providing situational awareness and enabling dynamic adjustments to airspace availability.

By leveraging automation, LAANC reduces the need for manual coordination, allowing for near-instantaneous authorizations and efficient management of low-altitude airspace. The concept of ATC Preapproved Terminal Airspace Areas proposes extending the model of designated airspace where Part 107 sUAS operators are able to operate in terminal airspace like it was Class G to higher terminal airspace altitudes.

4.3.2. Facility-Determined Airspace Availability Based on Operational Patterns

Using LAANC and the UAS Facility Maps as precedent, the subgroup discussed how individual ATC facilities possess unique insights into their local airspace, including traffic flows, peak activity periods, areas of congestion, and areas of low utilization. ATC Preapproved Terminal Airspace Areas could take the shape of “corridors”. By utilizing automation, facilities can:

- **Customize Airspace Segments:** Define specific volumes of airspace where Technology-Enabled Operations could occur without interfering with typical crewed aircraft operations or requiring additional ATC resources.
- **Adjust Availability in Real Time:** Modify the status of preapproved airspace areas based on current conditions. For example, if a typically underused area experiences increased crewed traffic due to a special event, the facility could temporarily suspend authorizations for Technology-Enabled Operations in that area.
- **Enhance Situational Awareness:** Maintain an up-to-date picture of all airspace users through automated data exchanges, supporting better decision-making and conflict prevention.

This localized approach allows for flexibility and responsiveness, ensuring that uncrewed operations are integrated safely and efficiently according to the unique characteristics of each facility's airspace.

4.3.3. Operating Class B, C, and D, Airspace Like Class E for Authorized Users

By effectively operating controlled airspace classes in a manner similar to Class E airspace for authorized users, the subgroup discussed how the airspace system could achieve greater efficiency through:

- **Reduced Need for Voice Communications:** Automation and other technologies could reduce reliance on traditional voice communications with ATC, which can be a limiting factor in m:N operations. Remote pilots could receive necessary information and authorizations digitally.

- **Operator Responsible for Separation:** Similar to VFR operations in Class E airspace, VFR-like Technology-Enabled Operators would be responsible for maintaining separation from other aircraft using onboard detect-and-avoid and other technologies (see section 3.2).
- **Streamlined Procedures:** Simplifying procedures for access to airspace could reduce administrative burdens and encourages compliance among operators.

Technology-Enabled Operations that occur in ATC Preapproved Terminal Airspace Areas are expected to be transiting through the airspace and may be using non-towered airports or vertiports not the runways for the airport which defines the terminal airspace. This is somewhat similar to the cooperative area and corridor concepts espoused in other concepts [26, 27, 28, 29].

4.3.4. Incorporating Automation Technologies

The subgroup discussed that the success of this concept would rely heavily on the incorporation of advanced automation technologies, potentially including the following:

- **UAS Traffic Management (UTM) Systems:** Expanding the implementation of sophisticated UTM systems that could manage high volumes of unmanned aircraft operations, providing services such as strategic deconfliction, route planning, and dynamic re-routing.
- **Integration with ATC Systems:** Ensuring that automated systems used by operators are interoperable with existing ATC systems, facilitating seamless data exchange and situational awareness for controllers.
- **Artificial Intelligence and Machine Learning:** Utilize machine learning algorithms to analyze airspace data, predict traffic patterns, and optimize airspace utilization. Machine learning and other artificial intelligence techniques could also assist in detecting potential conflicts and suggesting resolutions before they escalate.

The integration of automation into airspace management supports scalability through handling a high volume of authorization requests and adjusting airspace availability dynamically, supporting the growth of unmanned aircraft operations. Additionally, increased automation could lead to safety enhancements by reducing human error in authorization processing and may provide real-time monitoring of airspace, alerting remote pilots and ATC to potential conflicts. And finally, automation could lead to increased operational efficiency by streamlining processes to reduce delays and enable remote pilots to plan and execute missions more effectively.

Areas Requiring Further Study

- **Conflict with IFR traffic:** What procedures are needed to address scenarios where IFR traffic needs to enter the preapproved areas? Strategies could include temporary suspension of Technology-Enabled Operations, automated alerts to operators, or dynamic airspace status updates to prevent conflicts. The latter would require management of both IFR and VFR operations through the same interface and system.
- **Automation Support for Airspace Status Changes:** What will be the process for real-time systems to receive updates on airspace availability? It is essential that automated system should promptly communicate changes in airspace status to remote pilots, ensuring they can adjust operations accordingly.
- **Operator Compliance and Situational Awareness:** What processes and procedures will ensure operators are promptly informed of and comply with airspace status changes? This may involve developing robust communication protocols and fail-safes within the automated system.
- **Regulatory Adjustments:** Will there be the need for regulatory adjustments to enable ATC Preapproved Terminal Airspace Areas for Technology-Enabled Operations? There was no regulatory language needed to implement LAANC because there was enabling language in Part 107 regarding the permission to operate sUAS in the surface area of Class B, C, and D airspace with prior authorization of ATC [30]. Can such an approach be implemented with procedural changes and changes to the AIM [21] and FAA Order 7110.65 [23] alone?
- **Impact on ATC Workload:** Although the approach discussed by the group aims to minimize potential increases in ATC workload, would a comprehensive assessment be necessary to confirm that it does not increase complexity or introduce safety risks, particularly during dynamic airspace status changes.
- **System Interoperability and Standardization:** Ensuring that different automated systems used by operators and ATC can communicate effectively is critical. What ATM system changes would be necessary including potentially standardization of data formats, communication protocols, and automation tools?

5. Leverage Ability to Transition Between m:N and 1:1

When the subgroup first began discussing the concept of Technology-Enabled Operations, discussion quickly turned to how such a concept might work for aircraft intending to operate to or from the airport which defines Class B, C, and D airspace. The ATC Preapproved Terminal Airspace Areas discussed in Section 4, might enable operations that may transit Class B, C, and D airspace or operate to/from vertiport, heliports, or non-towered airports which happen to be in Class B, C, and D airspace. VFR operations today require clearance to land, two-way communications with controllers, and in the case of Class B airspace, permission to enter.

The subgroup discussed that an option for flights that operate to/from airports that define Class B, C, or D airspace or where it is not feasible for ATC to Preapprove Airspace Areas for Technology-Enabled Operations, is that these flights could operate under the existing IFR procedures with a Remote pilot ratio of 1:1 (i.e., one flight per RPIC). Flights could start IFR at 1:1 and then transition to m:N/Technology-Enabled Operations once they have entered Class E airspace or airspace ATC preapproved for Technology-Enabled Operations. This would be similar to how in today's operations, an IFR flight can "cancel IFR" in flight, thus starting as an IFR and become a VFR. Likewise, a VFR flight can "file enroute" or pick up a pre-filed IFR clearance enroute and transition from being VFR to IFR.

Thus, as the subgroup discussed, the entire end-to-end operation does not necessarily need to be m:N using the Technology-Enabled Operations ideas discussed in Section 3. An individual flight could transition from m:N/Technology-Enabled Operations to 1:1/IFR and back again as needed to transition specific airspace. As an example, a flight could start its operation as an IFR operation with a single remote pilot talking to ATC as it departs a Class C airport. As it transitions into Class E airspace, the RPIC could cancel the IFR flight plan and start operating under the Technology-Enabled Operations ideas discussed in Section 3. The RPIC could then transition to m:N operations following appropriate procedures as defined in the operator's operational specification approved by the regulator. As the subgroup discussed, perhaps the flight could continue to operate as a Technology-Enabled Operation for the duration of the flight or transition back to 1:1 remote pilot operations and become a "pop-up" IFR flight as it gets ready to enter airspace which cannot support Technology-Enabled Operations.

The subgroup also discussed that 1:1 operations may be a reversionary mode that is used during an aircraft emergency or other aircraft contingency. This may occur whether or not ATC services are required for the contingency.

Areas Requiring Further Study

- How would this transition work from the operator's perspective?
- How would this transition work from ATC's perspective?
- What would be the appropriate operational procedures to ensure that the operator maintains operational control?
- Would this increase controller workload with potentially a greater number of "pop-up IFR" flights?
- Would increased numbers of "pop-up IFR" flights disrupt traffic management initiatives put in place for demand capacity balancing purposes?
- What pre-flight information needs to be shared with other operators and ATC?

6. Alternative Approach: One RPIC to One ATC Sector (i.e., Controller)

Remotely piloted aircraft operating as traditional IFR under m:N operations would typically imply that one remote pilot may be simultaneously overseeing multiple flights that are operating in different ATC sectors on different frequencies. That means that the remote pilot's attention may be split among operations that are simultaneously executing different procedures and could result in a loss of situational awareness about the airspace in which each individual flight is operating. More than one controller on different frequencies may be issuing instructions to a single remote pilot at the same time resulting in delayed or missed communications and potential confusion. In the future, assistive technologies leveraging speech recognition might be employed. Even then, these technologies might fall short of fulfilling the necessary situational awareness that remote pilots would need to appropriately interact with controllers including accepting and appropriately following controller instructions and clearances.

While much of the subgroup discussion focused on mechanisms to eliminate the need for routine ATC services and controller voice communications for m:N operations, the subgroup also discussed another operational implementation which might be applicable. This alternative approach involves aligning remote pilot responsibilities for multiple flights to flights that are contained in a single ATC sector. This effectively creates a one-to-one relationship between the remote pilot (responsible for multiple flights) to a single controller responsible of sector containing those flights. The remote pilot would be communicating on a single voice channel with a single controller. There would be little increase in the probability of step-on's, missed transmissions, or other voice communication challenges than those associated with today's pilot-controller voice communications. Since most of the “flying” behaviors are highly automated and remain onboard the aircraft, the remote pilot could focus their situation awareness on the airspace in which all of their flights are operating, facilitating more effective interchanges with ATC.

In the subgroup discussion, it was postulated that as the aircraft progresses from sector-to-sector and ATC controllers hand-off control to a neighboring sector, remote pilots could similarly transition responsibility for flight operations to another remote pilot (the assumption being that these remote pilots are all part of the same operator). Thus, the operator would need a remote pilot for every sector that they anticipate their aircraft would transit. This approach may only be viable for some kinds of operational business models. This approach is also similar to practices used for ATC training as well as human-in-the-loop simulation studies. In this case these multi-aircraft simulated pilots are referred to as “pseudo-pilots” responsible for the input of command for all the aircraft within the same sector [31].

For such an approach to be viable, assurance of appropriate information sharing is critical and requires research into assurance of a proper hand-off for the safety of flight and the required items that need to be included during this procedure.

The subgroup discussed that some of the benefits of this alternative approach include higher situational awareness of all participating and non-participating aircraft operating in the vicinity of multi-aircraft operations, as well as general mental picture of the airspace status for the remote pilot. This approach also might allow operators to increase operational tempo faster.

The subgroup discussed some challenges of this alternative approach as well. Tighter relationship between m:N operators and ATC facilities in the projected area of operations will be required to ensure appropriate staffing and frequency allocation on the operator side. Due to the dynamics in the ATC environment, sectors can often be split or combined, which would lead to unexpected frequency changes for the multi-aircraft operators and potentially pose safety implications raising from uncertainty. Another challenge that could pose an issue is vectoring or rerouting into a sector that might not have an allocated remote pilot to be handed off to, which, again, could raise uncertainty and might compromise safety of the operation. The subgroup discussed that as IFR procedures would need to be followed, this may result in significant separation requirements and circuitous routings. Last but not least, remote pilots and controllers have different responsibilities and legal authorities/implications, which makes “hand-offs” different in nature for these operational performers.

There are still many unknowns to this alternative approach and much research would be needed to determine if it could be conducted safety and to develop the appropriate procedures. As the subgroup discussed, this alternative approach has a potential to pinpoint a path to enabling high-density m:N operations with a potential to minimally impact ATC.

Areas Requiring Further Study

- What will be the impact on controller workload?
- Can a RPIC maintain the appropriate level of situation awareness?
- Does the approach reduce the voice communications problems of m:N operations?
- Will IFR procedures (e.g., separation and spacing requirements; routings) result in inefficiencies that reduce the utility of this approach?
- What are the appropriate RPIC hand-off procedures?
- How will ATC sector management decisions impact RPIC staffing?
- Will frequent hand-offs of authority, responsibility, and accountability among remote PICs introduce additional hazards and risks?
- Is there a potential for ATC to confuse aircraft interactions and procedures since the verbal response for positive acknowledgement of instructions will be from the same voice?

7. Challenges and Areas Requiring Further Analysis

Today’s airspace operational procedures and technologies are a result of a long term, complex evolution given rise to existing operations that are safe, orderly, and efficient. Enabling new entrants to conduct m:N operations, an unprecedented mode of operation, is challenging for a myriad of reasons (see section 1.2). The aircraft involved with m:N operations would be uncrewed (i.e., no pilot onboard) raising questions about which “piloting” functions need to be maintained onboard through automation and which must be performed by a human remote pilot on the ground. What level of situational awareness related to flight management does the remote pilot need especially if they are supervising multiple flights simultaneously? Most importantly to the airspace integration subgroup was questions about how such operations could safely and efficiently co-exist with existing flight operations.

As the subgroup explored and discussed concepts for operational integration of m:N operations, they identified several challenges and open questions. Many of these were captured in highlight boxes in the previous sections. This section attempts to summarizes those challenges identified.

7.1. Challenge – Technology Readiness

Clearly, for the concepts discussed in this white paper to be viable there would be a significant reliance upon technology including sensors, communications, and automation algorithms that are able to determine appropriate courses of action, safely and reliably. Are currently available advanced technologies mature enough to support an appropriate response enabling Technology-Enabled Operations? What is required for the technology to be demonstrated to safely perform its intended function? What is the path for certification and operational approval for these technologies, their intended use, and their operational design domain? Can the necessary high availability and low latency be guaranteed? Can these processes move quickly enough to match market demand for m:N operations? Can the development and application of these processes aligned with time expectations of the market pull from the potential m:N operators?

7.2. Challenge – Identification of Functional Requirements for m:N Operations

To operate m:N, it will be important to identify and explicitly list the piloting functions that need to remain on board the aircraft and thus fully implemented in automation. To achieve an operational paradigm for m:N operations, there are necessary technological advances for multi-aircraft control from the perspective of human-machine teaming that work together to fulfill the duties of multiple crews for multiple aircraft that occur in current flight operations today. This should be achieved so that m:N operations do not differ from any other operation in the airspace. That being said, the performance metrics of human and machine/autonomy may need to be assessed separately first in order to ensure that the operational application and requirements could be appropriately performed [32].

Technological challenges require further exploration around what automation features need to be developed along with other technical and regulatory advancements that achieve the desired functionality of this paradigm. While the subgroup recommends is no particular set of technical advancements, the solutions may have costs and functional trade-offs that are not yet fully understood. The higher the ratio of aircraft to remote PIC, the more automation and autonomy features the system must have (e.g., onboard the aircraft, in Ground Control Station (GCS), or in the cloud). Beyond that, the kinds of automation and technical advancements needed to achieve the desired functionality at higher ratios might differ depending on the technical and regulatory approach . Additionally, the cost and regulatory effort that would be required to achieve the higher m:N ratios might be greater than expected and difficult to adopt broadly. This kind of trade space is largely undefined, but it is a critical step to definition and analysis on the combinations of technology solutions for the progression of automation technology on the m:N roadmap.

7.3. Challenge – Lost Command and Control Link Implications

While the remote pilot is not directly controlling the flight control surfaces of the aircraft and is most likely providing high-level management and oversight of the operation, in a “lost command and control (C2) link” scenario, the remote pilot and thus the operator is no longer able to maintain direct operational control[i] of the aircraft. The subgroup discussed that while much of the aviate and navigate functions are fully automated on-board the aircraft, there are certainly implications for concepts like Technology-Enabled Operations if the remote pilot is no longer able to maintain situation awareness and provide guidance as may be necessary for the flight operation. In addition, automation on-board the aircraft may no longer be receiving information updates from

[i] Per 14 CFR § 1.1, Operational control, with respect to a flight, means the exercise of authority over initiating, conducting, or terminating a flight.

ground automation systems. Any safety case associated with Technology-Enabled Operations must take in to account the risks associated with the hazard of lost command and control communications including the potential for multiple and potentially large numbers of aircraft to loose communications at the same time. In addition, specific procedures may be necessary for the aircraft to follow. It is important for the operation to continue to behave in an expected and predictable manner from the perspective of ATC and other airspace users in the airspace. In general, when compared to IFR operations, ATC has less predictability about today's traditional VFR traffic and may have a similar level of predictability about Technology-Enabled Operations even though there is an opportunity for the sharing of some operational intent data.

Perhaps lost c2 link procedures for Technology-Enabled Operations could leverage the procedures associated with unmanned aircraft [33] which have mainly focused on deterministic procedures. Depending upon the communications architecture, the operator (e.g., remote PIC) could be able to communicate directly with ATC and relay the action that the aircraft is expected to be taking. The on-board DAA systems would likely continue to function but may be limited in that it would not be able to depend upon information updates from ground systems and would only be able to rely upon information that is able to be directly sensed on-board whether by non-cooperative or cooperative surveillance sensors.

Expected and predictable behavior will be important and may depend upon many factors including where the aircraft is in its mission profile. For example, the safest option may be for the aircraft to continue on the mission and land at the intended destination. If the aircraft needs to deviate, it should be able to do so in an expected and predictable manner (perhaps similar to a traditional VFR flight) for continued safe flight and landing.

7.4. Challenge – High Decision Tempo Situations

There are some situations and phases of flight where a lot of significant operational decisions need to be made that may involve significant interactions with the operational environment including other aircraft. These may include ground operations as well as approach and landing. The subgroup discussed that at least initially, perhaps in these high decision tempo situations, rather than continuing to operate m:N, the flights might revert to a 1:1 schema while still operating as Technology-Enabled Operations (similar to Section 5). Such a phased implementation approach may make the initial safety case more viable but raises challenges associated with staffing and operational management to ensure a remote pilot is available and situationally aware when required.

7.5. Challenge – Perspective of ATC of VFR Equivalent Operations

The subgroup discussed that while like traditional VFR operations today, ATC may not have direct responsibility for separating Technology-Enabled Operations, they would need surveillance information to maintain airspace awareness. What information will ATC need about what operations occurring in ATC Preapproved Airspace? Should Technology-Enabled Operations targets be distinguishable for traditional VFR targets on their displays? How can we best ensure that controllers have the information they need and are not overburdened with information for which they cannot act upon? Will ATC need pre-flight information, especially if an operation may start as a Technology-Enabled Operation and then intends to become an IFR operation as it transitions into terminal airspace?

7.6. Challenge – Role of Third-Party Service Providers

The subgroup discussed that third-party service providers may have a role in providing validated safety critical information to the automation systems used to conduct highly automated flight operations. If information is safety critical, the regulator would require a mechanism for safety oversight. The subgroup briefly discussed the potential for third-party service providers to have a role in facilitating the sharing of information and potentially coordinating operations among different operators.

7.7. Challenge – Remote Pilot Duty Time Requirements

The subgroup discussed that the role of a remote pilot, especially one responsible for multiple aircraft at the same time may have implications for cognitive workload and fatigue. Will there be the need for new rest requirements for m:N remote PICs? Are there implications for the duty day limits? What are the implications for shift transitions and relief briefings?

7.8. Challenge – Advancements Need an Understanding of the Technology Trade Space

From the perspective of the well-known piloting principles: *aviate*, *navigate*, and *communicate*, a lot of the *aviate* and *navigate* behaviors and subsequent decision-making would be highly automated and codified to ensure that the aircraft is able to fly on its own and execute the missions that are intended by the remote pilot. While the following paragraphs will draw the parallel to the legacy “aviate, navigate, communicate” functions, it is well understood and discussed by the subgroup that these principles will need to be expanded or amended for multi-aircraft operations relying on higher level of automation in order to better apply to intricacies of operational scenarios they are involved in.

Critical safety behaviors (e.g., DAA) often lie on that spectrum, where proper airspace integration would require codifying the rules of the air and the expectation of a human-like response. *Communicate* behaviors could be automated, although, nominal human interactions would be expected as part of the standard operations. Acknowledging that not everything can be offloaded to automation, there would be challenges with integration into non-towered aerodromes that require announcements on a common traffic advisory frequency (CTAF) and sequencing into the traffic pattern. In this case, the aircraft would need situational awareness about the pattern, aircraft in that pattern, and what is the likely intent for each of those aircraft. The question here becomes whether it is the system that should interpret speech and understand the intent or whether that could and should be off-loaded to a human component. In a larger scheme of things, it could be a combination of both with a different level of system automation and infrastructure that supports the multi-aircraft operations.

A comprehensive integration into the NAS requires a variety of combinations for operational applications and requirements for aircraft capabilities and infrastructure capacities that may cater to all aviation stakeholders and not only multi-aircraft operations. To that extent, multi-aircraft operations need to be ready to fulfil the requirements for all the various environments they are integrated into. For example, integration of few operations per day to an aerodrome may require some unique system automation on the operator side, while integration of hundreds of multi-aircraft operations may need to consider deployment of additional new infrastructure in its support. The remote pilot in m:N operations should interface with aircraft such that tasks are prioritized in a way that allows the remote pilot to understand when exceptions occur, manage those exceptions, and then to distribute management plans to the aircraft.

7.9. Challenge – Availability of Technology Improvements

Within the space of technical advancements, the subgroup discussed that m:N operations would likely require some upgrades to technology and the Communications, Navigation, and Surveillance (CNS) infrastructure within the operational environment:

- **Traffic Surveillance** would be needed to ensure that automation systems have the appropriate situation awareness of traffic including other Technology-Enabled Operations, IFR, and traditional VFR including those that are not participating in the cooperative surveillance system (i.e., without ADS-B or Mode C transponders). Surveillance technology would likely require high update rates, improved accuracy, high availability, appropriate security, and expanded coverage.
- **High-Integrity Precision Navigation** to enable Technology-Enabled Operations to accurately navigate and follow their intended route of flight in a safe and efficient manner and at high volumes. More precision landing infrastructure at the aerodromes would allow for wider adoption of m:N operations. Dependency upon GNSS-based navigation needs to be addressed especially as vulnerabilities to jamming and spoofing are being exploited.
- **Improved ATM Communications** including more automated and/or digital means of communication and direct linkages to the remote pilots when necessary.
- **Improved Aircraft-to-Aircraft Communications** could allow for safe high tempo m:N operations. The data sharing and data exchanges between participating aircraft may improve traffic situation awareness and potentially the coordination of conflict avoidance maneuvers.

7.10. Challenge – Cloud Clearance Requirements and Operations in IMC

As the subgroup discussed, one potential advantage of Technology-Enabled Operations is the ability to operate with the flexibility of VFR with some of the benefits of IFR (e.g., operating in IMC). m:N operations would rely on DAA systems to remain well clear of other aircraft and ensure collision avoidance. Depending upon the technology involved, meteorological conditions limitations may not play the same role during flight planning or execution. While there may be new limitations based upon the sensor technology employed, remaining clear of clouds to ensure a human pilot's ability to visually see other aircraft may not be required. The subgroup discussed that since Technology-Enabled Operations behave in a manner effectively equivalent to traditional

VFR they would likely operate at VFR altitudes while remaining electronically aware of IFR operations. In IMC, an IFR pilot would not likely expect any VFR aircraft and thus would not be expecting aircraft at VFR altitudes. Could this create safety challenge? Collision risk modeling would likely be needed to determine if there are implications that may influence the collision risk ratio.

8. Key Enablers

The subgroup discussed that multi-aircraft operations can build on the many enablers that either exist today or can be borrowed from developments used for routine UAS integration into the NAS. Multi-aircraft operations would require a combination of novel onboard systems, information sharing, data exchange, and coordination for resource usage between various stakeholders, where all tie into notions for conflict and airspace management.

8.1. Conflict Management Framework and DAA

A Conflict Management Framework (CMF) including DAA technology is one of the most important components for uncrewed multi-aircraft operations. Legacy systems currently used for conflict management today (e.g., ERAM, STARS) were not intended for the kinds of aircraft system automation needed for m:N operations and are heavily reliant on human involvement. It is beyond the scope of this paper to discuss the specifics of a CMF to enable Technology-Enabled Operations, but the subgroup did explore the topic briefly.

Strategic deconfliction commonly happens today in form of Demand and Capacity Balancing (DCB), flight planning, allocating resources, and traffic flow management. As the subgroup discussed, this pillar could be foundational for many multi-aircraft operations as it is essential to ensure that every operation is properly supported by resources and does not cause overload the ability for the separation provision layer to address tactical conflicts. While strategic deconfliction is intended only for allocating access to specific capacity constrained resources and other known flight plans/operational intents, it could help ensure that the operations would not constrain other airspace users. Preapproved airspace areas that are coordinated with ATC would also fall in this domain, as they are a resource that these operations could use and be deconflicted against. Strategic deconfliction utilizes data that is available for flight planning and resource checking, as well as all available operational intent that could be used for deconfliction. While it is notionally an ATC role to ensure proper DCB and resource availability, the subgroup discussed that there is an opportunity to add another coordination layer through third-party services. These services could facilitate the exchange of more detailed operational intent that could be easily cross checked across all the other operators. This ensures proper coordination among operators and cross checked among operator deconfliction practices, as well as any imposition on future operations that have submitted their intent to ATC. The main purpose of the strategic conflict management layer is to ensure that the next layer (i.e., separation provision) is able to function effectively.

Separation provision is more of a tactical deconfliction capability that is often provided as ATC services but could also include VFR operations where the pilots visually remain “well clear” of traffic and other hazards. Technology-Enabled Operations are primarily concerned with this layer where DAA and other automation on-board the aircraft and employed by the remote PIC is ensuring aircraft remain safely separated and well-clear of traffic hazards. DAA technology including both cooperative and non-cooperative surveillance sensors as well as avoidance algorithms would be a key enabler.

Collision Avoidance is the last layer of conflict management and for unmanned aircraft is achieved by employing DAA technology . This layer only plays a role when there is a failure in the separation provision layer. It is important to establish a CMF that addresses appropriate solutions at all three layers of the ICAO conflict management model.

8.2. Continuous Independent Validation

Since m:N operations would rely heavily upon automation, the subgroup discussed how it would be important to continuously validate sensor data and aircraft automation behaviors. More advanced anomaly detection algorithms and schemes will enable real-time monitoring and feedback to remote pilots that maintain safety by keeping a constant situational awareness and involve a human for managing and mitigating exceptions when necessary (e.g., certain failure modes, emergencies). With advanced automation, anomaly detection would be a critical part of the infrastructure since there may be failure conditions that were not considered in the system design (e.g., unknown unknowns).

8.3. Information Services

The subgroup discussed a variety of information services that would help enable Technology-Enabled Operations and the creation and utilization of ATC-Preapproved Airspace Areas. The subgroup discussed the likelihood of many of these information services could be provided by third parties. While it was beyond the scope of the subgroup to provide details, these information services could potentially include the following elements:

- Mechanism for sharing operational intent including IFR Flight Plans
- LAANC-like capability for authorization to use preapproved areas in Class B, C, and D airspace
- Authoritative geo-referenced terrain, obstacle, and other aeronautical data
- Weather information including wind, visibility, ceiling, and precipitation
- Notices to Airman (NOTAMs)
- Communications coverage
- Ground-based traffic surveillance data and coverage information
- FAA surveillance information including potentially primary radar returns and coverage information
- Navigational performance including Receiver Autonomous Integrity Monitoring (RAIM) coverage, jamming/spoofing areas, etc.

9. Summary

This white paper presented thoughts on potential mechanisms for routine airspace integration of m:N operations as discussed by a collection of subject matter experts. These experts met multiple times over a period of several months where they discussed and explored mechanisms that might enable routine m:N operations in non-segregated airspace as part of a NASA working group on multi-aircraft operations. The full working group recognized that a potential barrier to routine m:N operations is the existing human-centric approach to ATC services for IFR flights and the dependence upon voice communications between the remote pilot and ATC. With the exception of small UAS flying under 14 CFR Part 107 operating rules, most uncrewed operations occur as IFR today. The working group explored whether it is possible to reduce and/or eliminate the need for ATC services for m:N operations, and thus eliminate the voice-communication barrier associated with interaction between the remote pilot and the ANSP. The airspace integration subgroup was formed to explore potential mechanisms that could possibly be implemented in the next decade following the implementation of the FAA's BVLOS rule.

The subgroup discussed a strategic approach towards minimizing routine interactions with ATC that has three specific components as follows:

- Technology-Enabled Operations that behave in a manner equivalent to VFR operations
- ATC Preapproved Terminal Airspace Areas
- Transition Between m:N Operations and Operations with a Single Dedicated Remote Pilot

Recognizing that Technology-Enabled Operations are not the only feasible approach, an alternative idea on aligning remote pilot and controller responsibilities is also presented. It is beyond the scope of this paper to consider all alternatives and to analyze the relative trade-offs among the alternatives presented. The paper identified key enablers, potential challenges, and areas requiring further study to inform community dialog moving forward.

10. References

[1] Department of Transportation Rule-making information site. https://www.reginfo.gov/public/do/eAgendaViewRule?pubId=202404&RIN=2120-AL82, Accessed 21 February 2025.

[2] National Academies of Sciences Engineering, and Medicine, *Advancing Aerial Mobility – A National Blueprint*, 2020. https://nap.nationalacademies.org/catalog/25646/advancing-aerial-mobility-a-national-blueprint Accessed 21 February 2025.

[3] Ben Goldstein, Aviation Week, FAA Approves Wing, Zipline BVLOS Drone Ops In Dallas, July 31, 2024 https://aviationweek.com/advanced-air-mobility-departments/faa-approves-wing-zipline-bvlos-drone-ops-dallas, Accessed 27 August 2024.

[4] Boeing Wisk, Concept of Operations for Uncrewed Urban Air Mobility Version 2.0, https://wisk.aero/wp-content/uploads/2023/12/Concept-of-Operations-for-Uncrewed-Urban-Air-Mobility-v2.0.pdf, 2023, Accessed 27 August 2024.

[5] Title 14 Code of Federal Regulations, Part 107 *Small Unmanned Aircraft Systems*.

[6] Federal Aviation Administration, Aeronautical Information Manual, https://www.faa.gov/air_traffic/publications/atpubs/aim_html/

[7] Federal Aviation Administration, LAANC, https://www.faa.gov/uas/getting_started/laanc

[8] International Civil Aviation Organization, “High-Level Concept Paper on a Changing Environment for Flight Rules,” ICAO Drone Enable, https://www.icao.int/Meetings/DRONEENABLE4/Documents/High%20Level%20Concept%20Paper%20on%20a%20Changing%20Environment%20for%20Flight%20Rules_DRONE%20ENABLE.pdf, Accessed 26 June 2022.

[9] National Academies of Sciences, Engineering, and Medicine, “Advancing Aerial Mobility: A National Blueprint,” The National Academies Press, https://nap.nationalacademies.org/catalog/25646/advancing-aerial-mobility-a-national-blueprint, Accessed 4 December 2024, Washington DC, 2020.

[10] Airbus, "Blueprint for the Sky: The Roadmap for the Safe Integration of Autonomous Aircraft," A^3 by Airbus LLC, https://storage.googleapis.com/blueprint/Airbus_UTM_Blueprint.pdf, Accessed 4 December 2024, Sunnyvale, 2018..

[11] EmbraerX, Atech and Harris Corporation, "Flight Plan 2030: An Air Traffic Management Concept for Urban Air Mobility," EmbraerX, https://daflwcl3bnxyt.cloudfront.net/m/4e5924f5de45fd3a/original/embraerx-whitepaper-flightplan2030.pdf, 4 December 2024, São Paulo, 2019.

[12] D. P. Thipphavong, R. D. Apaza, B. E. Barmore, V. Battiste, B. Burian and et. al., "Urban Air Mobility Airspace Integration Concepts and Considerations," in AIAA Aviation Forum, Atlanta, 2018.

[13] Lascara, B., Lacher, A., and et al,“Urban Air Mobility Airspace Integration Concepts - Operational Concepts and Exploration Approaches,” https://www.mitre.org/sites/default/files/publications/pr-19-00667-9-urban-air-mobility-airspace-integration.pdf, Accessed 26 June 2022, The MITRE Corporation, McLean, Virginia, June 2019.

[14] Drouilhet, Paul, "Electronic Flight Rules (EFR)-A Concept for Enhanced Freedom of Airspace," SAE Technical Paper 800735, March 1980.

[15] Wing, D. J., Lacher, A. R., and et al “Digital Flight: A New Cooperative Operating Mode to Complement VFR and IFR” NASA/TM– 20220013225, https://ntrs.nasa.gov/api/citations/20220013225/downloads/NASA-TM-20220013225.pdf, Hampton, Virginia, September 2022.

[16] Wing, David J., and William B. Cotton. “Autonomous Flight Rules-a Concept for Self-Separation in US Domestic Airspace”, https://ntrs.nasa.gov/api/citations/20110023668/downloads/20110023668.pdf, No. NASA/TP–2011-217174, Hampton, Virginia, November 2011.

[17] Sievers, T. F., Geister, D., Schwoch, G., Peinecke, N., Schuchardt, B. I., Volkert, A., & Lieb, T. J., “DLR Blueprint – Initial ConOps of U-Space Flight Rules (UFR),” https://www.dlr.de/en/fl/media/publications/reports/2024/dlr_blueprint_ufr_conops.pdf, Accessed 4 December 2024, DLR Institute of Flight Guidance, March 2024.

[18] Title 14 Code of Federal Regulations, §91.155 *Basic VFR weather minimums*.

[19] Luccio, Mattero, *PNT by Other Means*, GPS World, 10 July 2023, Accessed 10 February 2025.

[20] International Civil Aviation Organization (ICAO), *Global Air Traffic Management Operational Concept*, Doc 9854, ICAO, Montreal, Québec, Canada, 2005.

[21] Federal Aviation Administration, *Aeronautical Information Manual (AIM)*, https://www.faa.gov/air_traffic/publications/atpubs/aim_html/, Accessed 18 December 2024.

[22] RTCA, Inc., DO-365C *Minimum Operational Performance Standards (MOPS) for Detect and Avoid (DAA) Systems*, Washington, DC, September 2022.

[23] Federal Aviation Administration, Order JO 7110.65AA - *Air Traffic Control*, https://www.faa.gov/air_traffic/publications/atpubs/atc_html/, Accessed 18 December 2024.

[24] D. A. Domino, D. Tuomey, A. Mundra and A. Smith, "Air ground collaboration through delegated separation: Application for departures and arrivals," *2010 Integrated Communications, Navigation, and*

Surveillance Conference Proceedings, Herndon, VA, USA, 2010 https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5503250, Accessed 18 December 2024.

[25] Federal Aviation Administration, FAA UAS Data Visulaization On-line Tool, https://faa.maps.arcgis.com/apps/webappviewer/index.html?id=9c2e4406710048e19806ebf6a06754ad, Accessed 18 December 2024.

[26] Federral Aviation Administration, “Charting Aviation’s Future Operations in An Info-Cenric National Airspace System,” FAA, Washington, DC, Sept 2022.

[27] Federal Aviation Administration, “Initial Concept of Operations for an Info-Centric National Airspace System,” FAA, Washington, DC, December 2022.

[28] Federal Aviation Administration, “Urban Air Mobility (UAM): Concept of Operations v2.0”, FAA, Washington, DC, April 2023.

[29] Federal Aviation Administration, “Upper Class E Traffic Management (ETM): Concept of Operations v1.0” FAA, Washington, DC, May 2020.

[30] Title 14 Code of Federal Regualtions, §107.41 *Operation in Certain Airspace.* https://www.ecfr.gov/current/title-14/section-107.41, Accesssed 19 December 2024.

[31] R. C. Rorie, C. Smith, G. Sadler, K. J. Monk, T. L. Tyson and J. Keeler, "A Human-in-the-Loop Evaluation of ACAS Xu," 2020 AIAA/IEEE 39th Digital Avionics Systems Conference (DASC), San Antonio, TX, 2020, https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=9256618, Accessed 31 December 2024.

[32] J. A. Adams, J. Hamell and P. Walker, "Can a Single Human Supervise a Swarm of 100 Heterogeneous Robots?," in *IEEE Transactions on Field Robotics*, vol. 2, pp. 46-80, 2025,

[33] RTCA Special Committee SC-228, DO-400 *Guidance Material: Standardized Lost C2 Link Procedures for Uncrewed Aircraft Systems*, RTCA Washington, DC, June 2023.

Appendix: Members of the Airspace Integration Subgroup

The individuals below participated in some of the face-to-face and virtual discussions related to airspace integration of m:N operations that are captured in this white paper. Participating in the discussion, does not imply organizational or individual endorsement of the contents of this white paper.

Andy Lacher	NASA (subgroup facilitator)
Adam Hendrickson	FAA - AFS
Chad Healy	Reliable Robotics
Derek Halpin	AeroVironment
Evan Maki	MIT Lincoln Laboratory
Holly Hughes	SkyGrid
Igor Dolgov	Reliable Robotics
Jason Prince	NASA
Jeff Homola	NASA
Jimmy Smith	NATCA
Justine Hong	Global Aerial Management Group
Keith Mottas	Atlantic Drone Pros
Lance King	Northrop Grumman Corporation
Mehrnaz Sabet	Cornell University
Mykyta Zhyla	Wisk
Paul Albuquerque	FAA - AFS
Raymond Adams	Airde Elevated Thinking LLC
Rob Knochenhauer	Censys Technologies
Sandro Salgueiro	SkyGrid
Timothy Bleakley	General Atomics Aeronautical Systems
Tom White	ATC SME
Vas Patterson	Air Line Pilots Association
Walter Jones	FAA Contractor
Walter Waltz	NASA
Wes Ryan	Northrop Grumman Corporation