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Enabling Scalable Urban Air Mobility Through Automated Flight Rules

WHITE PAPER

Foreword

AUTOMATED FLIGHT RULES

As aircraft with increasing levels of conflict management and decision-making automation are introduced into the global airspace system, operational procedures and traffic management approaches must evolve to support new mission types and to allow airspace users to fully leverage these emerging capabilities. SkyGrid and Wisk, alongside Boeing, propose that establishing a new set of flight rules tailored to these highly automated operations is a key step in this evolution.

The development of new flight rules is not without precedent. Aviation began with Visual Flight Rules (VFR), under which pilots operated independently using visual cues to navigate and remain clear of other aircraft. As operations evolved in performance, scale, and complexity, it became clear that the ability to safely operate at higher altitudes, higher speeds, and lower visibility conditions was essential. This drove new navigation and communication requirements and ultimately led to the development of Instrument Flight Rules (IFR), enabling safe operations across a broader range of weather conditions, cruise altitudes, and speeds. The introduction of IFR brought new airspace classifications, equipage and pilot qualification requirements, and the formalization of air traffic services. Throughout this evolution, the system remained human-centric, relying on human-compatible interfaces such as voice communications, preserving inclusivity for existing users while improving safety.

As the next step in this evolution, a new set of flight rules, termed **Automated Flight Rules (AFR),** is proposed to support operators of highly automated aircraft, including those capable of operating with reduced human involvement. AFR is designed to complement, not replace, VFR and IFR, and to be available to any properly equipped airspace user. Whereas VFR and IFR rely on pilot visual awareness and ATC-provided services to keep aircraft safely separated, AFR will allow aircraft to use automation to perform conflict management functions. Operators of uncrewed aircraft may additionally pair this capability with new decision-making automation, reducing the need for human involvement in operations. As a result, AFR will support the safe and scalable integration of increasingly automated aircraft into the global airspace system.

While a broader discussion of how AFR may be applied across a wide range of airspace users is the topic of a separate Boeing, SkyGrid, and Wisk AFR Concept of Operations document[1] , this white paper focuses specifically on how AFR can support the airspace integration of low-altitude Urban Air Mobility (UAM) operations[2] and their safe and efficient scaling beyond the constraints of the current airspace system. Rather than providing detailed technical specifications for new flight rules, this paper presents an overview of the basic operational procedures and behaviors expected of UAM aircraft operating under AFR. Future publications will address contingency procedures, minimum aircraft equipage, performance requirements, operational approval processes, and accountability frameworks for AFR. SkyGrid and Wisk hope that this document will stimulate fruitful conversations with regulators, Air Navigation Service Providers (ANSPs), and the wider UAM industry as we work together to advance the airspace integration of UAM worldwide.

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[1] *Available at https://www.boeing.com/content/dam/boeing/v2/company/innovation/innovation-concept-of-operations-for-automated-flight-rules.pdf.*

[2] *UAM operations are expected to be conducted below 4,000 feet above ground level (AGL).*

1.

Introduction

The Urban Air Mobility (UAM) industry is rapidly developing novel passenger-carrying, vertical takeoff and landing (VTOL) aircraft for short urban transport missions. While designing, building, and certifying these aircraft is a major technical undertaking, an equally significant challenge is integrating these new operations safely and efficiently into already complex urban airspace.

UAM operations are envisioned to reach high tempos, comparable to those of operations observed today at major airports, and primarily conducted at low altitudes below 4,000 feet above ground level (AGL). UAM aircraft will take off from and land at both existing airports and purpose-built urban vertiports. As a result, operations will be concentrated in dense and often constrained airspace environments, including airspace currently classified as Class B, C and D.

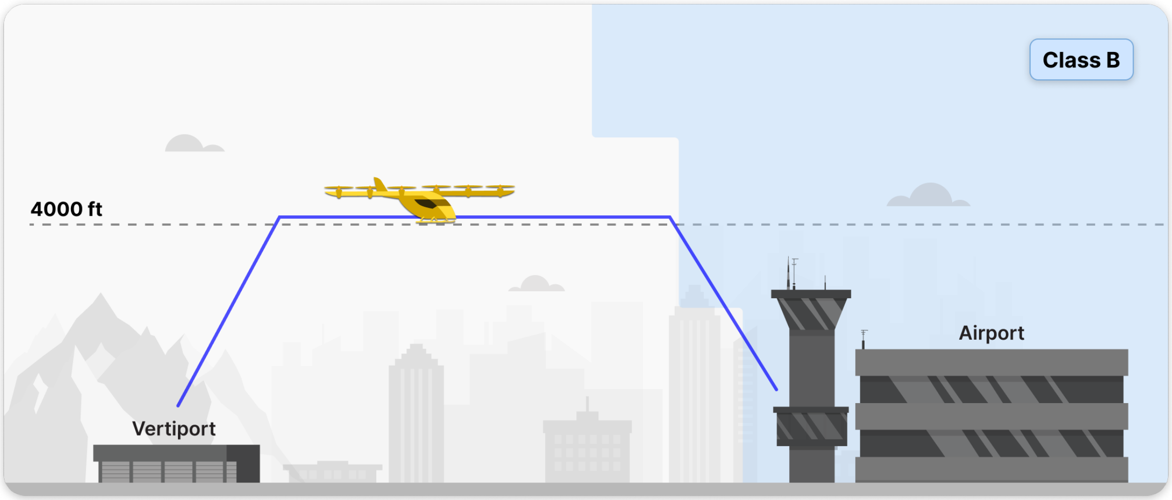

Figure 1. Typical UAM mission profile proposed by industry.

To safely and efficiently manage the increased complexity of high-tempo UAM operations in these airspaces without exceeding safe controller workload limits, SkyGrid and Wisk believe that UAM traffic must be primarily managed by automated traffic management systems, allowing air traffic controllers to focus on the strategic aspects of UAM traffic management while maintaining their existing airspace responsibilities.

Implementing this operational paradigm in low-altitude airspace is expected to require a coordinated, three-pronged strategy:

- Development of advanced traffic management automation that enables UAM aircraft to operate with reduced reliance on traditional air traffic services.
- Creation of new airspace structures, here referred to as Class X airspace, in which traffic management for UAM aircraft is provided by this new automation and which may be crossed by surrounding non-UAM traffic.[3]
- Establishment of a new operating mode, here termed Automated Flight Rules (AFR), that defines new operational procedures, required equipage, and operational approval processes for UAM aircraft relying on automated systems for conflict management, including those operating in Class X airspace.[4]

While UAM aircraft equipped with conflict management automation and operating under AFR will have access to all classes of airspace, operations in Class X airspace are expected to support significantly higher traffic densities. **This white paper focuses on describing how UAM operations will be conducted under AFR within Class X airspace, leveraging automated traffic management capabilities to enhance operational predictability, reduce reliance on pilot-to-ATC coordination, and support the high operational tempo required for scalable UAM operations.** The proposed concept is intended to apply to both crewed and uncrewed UAM aircraft.

The next section offers an overview of general AFR operations before transitioning to a focused discussion of AFR operations in Class X airspace. Readers seeking additional detail are encouraged to consult Boeing, SkyGrid, and Wisk's Concept of Operations for Automated Flight Rules.

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[3] It is assumed that a new separation paradigm, in which an automated traffic management system serves as the primary separator and communications are conducted exclusively through digital means, may require the introduction of a new class of airspace.

[4] While the introduction of AFR does not require the creation of a new airspace class, Class X is believed to offer unique throughput and capacity benefits to AFR operations.

2.

Overview of UAM Operations Under AFR

Today, aviation relies on two primary operating modes: Visual Flight Rules (VFR) and Instrument Flight Rules (IFR). These frameworks have supported modern aviation's safety, growth, and overall impact, yet they were not purposefully designed for increasingly automated aircraft, such as those equipped with conflict management and decision-making automation. Automated Flight Rules are intended to address this gap by providing operators of such highly automated aircraft with a third operating mode that complements VFR and IFR, enabling them to better leverage these capabilities to improve performance and airspace access.

UAM aircraft operating under AFR will be permitted to operate in all classes of airspace[5], and will use novel automated systems to perform functions traditionally assigned to human operators. The paragraphs below provide an overview of how UAM operations will be conducted under AFR in different classes of airspace:

- **Class B/C/D:** UAM aircraft operating under AFR will largely mimic IFR operations in these airspaces and be capable of flying instrument flight procedures. By leveraging high-assurance surveillance data and pairwise separation management capabilities, AFR aircraft will be able to accept delegated separation clearances from ATC without the need to visually acquire the target aircraft.
- **Class E/G:** UAM aircraft operating under AFR will largely mimic VFR operations and may operate without an ATC clearance. By leveraging high-assurance surveillance data and detect-and-avoid capabilities, AFR aircraft will be able to remain well clear of other traffic in the airspace without relying on pilot-applied see-and-avoid.
- **Class X:** UAM aircraft operating under AFR will be organized and separated by novel automated traffic management systems using all-digital communications, enabling structured, high-density operations without increasing the workload of air traffic controllers managing the surrounding airspace.

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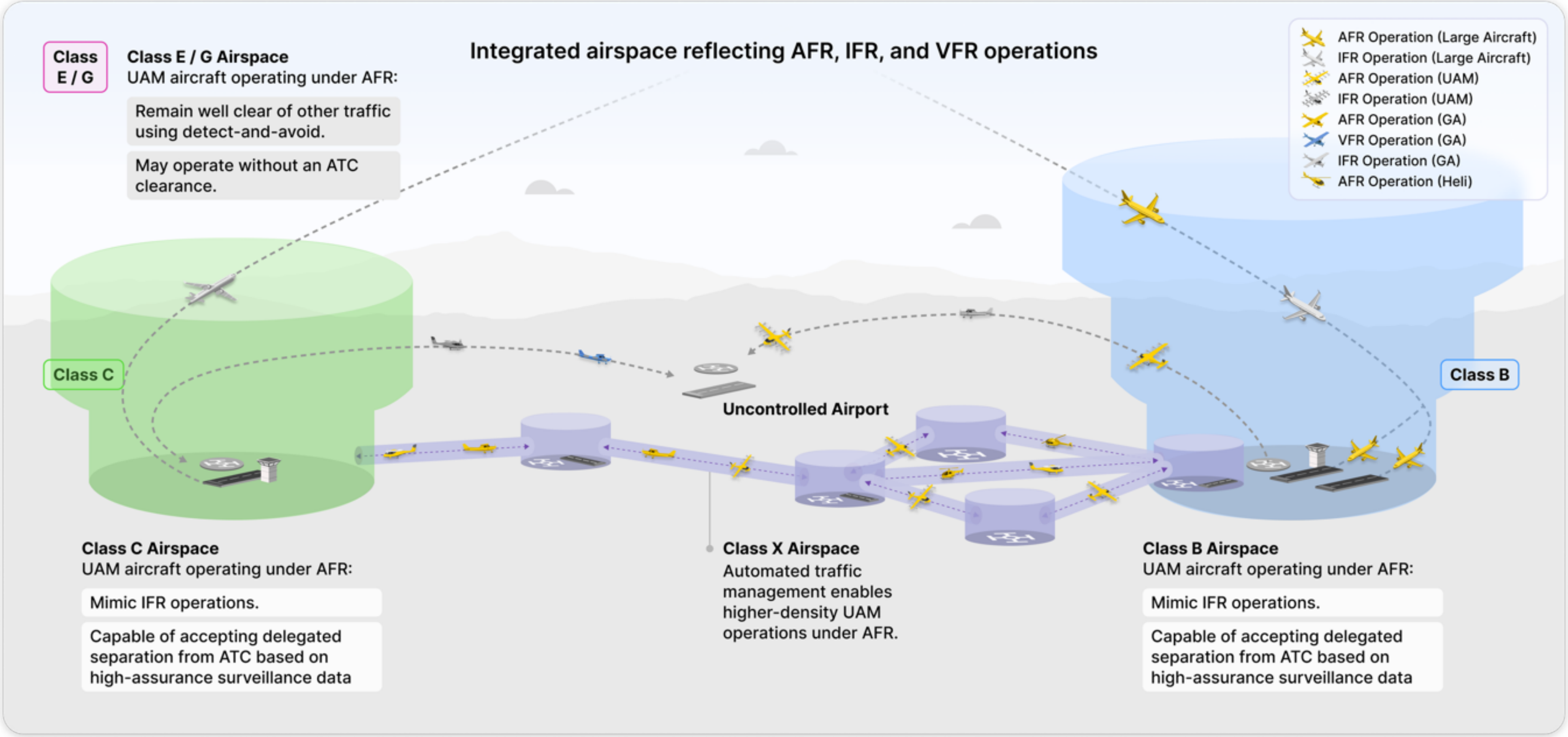
[5] *UAM aircraft will likely not operate in high-altitude Class A airspace due to constraints related to mission type and aircraft performance envelope.*



Integrated airspace reflecting AFR, IFR, and VFR operations

Class E / G Airspace
UAM aircraft operating under AFR:

Remain well clear of other traffic using detect-and-avoid.

May operate without an ATC clearance.

Class C Airspace
UAM aircraft operating under AFR:

Mimic IFR operations.

Capable of accepting delegated separation from ATC based on high-assurance surveillance data

Class X Airspace
Automated traffic management enables higher-density UAM operations under AFR.

Class B Airspace
UAM aircraft operating under AFR:

Mimic IFR operations.

Capable of accepting delegated separation from ATC based on high-assurance surveillance data

Figure 2. Notional depiction of UAM operations conducted under AFR in different classes of airspace. Class D not shown.

While Class X airspace is not required for the implementation of AFR, it has the potential to support AFR operations at a greater scale than other airspaces. Therefore, the remainder of this paper focuses on describing UAM operations within the Class X airspace depicted in Figure 2.

3.

Overview of UAM Operations in Class X Airspace

As with Class A airspace and IFR-only operations, establishing a dedicated airspace class for AFR operations will allow the full potential benefits of AFR to be realized, without the interoperability constraints present in other airspace classes. Class X airspace will enable automated systems to serve as the primary means of organizing and separating UAM aircraft. **This automation of traffic management functions, which reduces reliance on human-to-human coordination for safe and efficient operations, is expected to significantly enhance the scalability of UAM operations.**

In Class X airspace, UAM aircraft will operate along a low-altitude route structure connecting airports and vertiports throughout an urban region. The routes and procedures in this structure will use Required Navigation Performance (RNP) navigation specifications (NavSpecs) and have defined lateral and vertical paths that are, where possible, separated from existing instrument procedures used by traditional aircraft. In departure and approach segments, these routes may incorporate advanced operational concepts such as Established-on-RNP (EoR) and Multiple Airport Route Separation (MARS) to enable simultaneous independent UAM operations alongside conventional jet traffic. In cruise segments, each route may also have a corresponding, closely spaced, opposite-direction route to support two-way traffic. Multiple route options may be defined between UAM takeoff and landing sites to accommodate the different configurations of the surrounding airspace.

The airspace surrounding this route structure will be designated as Class X, which is assumed in this document to be a requirement for enabling a third separation paradigm beyond pilot-applied and ATC-provided separation. Similar in effect to VFR corridors and Special Flight Rules Areas (SFRAs) used today to accommodate higher-frequency VFR operations in Class B airspace in the United States, Class X airspace will relieve ATC of the responsibility for ensuring separation between AFR aircraft operating within it.

Instead, conflict management will be delegated to and performed by automation, distributed between ground-based and onboard systems. This will allow traffic density to scale within Class X airspace without corresponding increases in ATC workload.[6]

A ground-based system responsible for conflict management functions within Class X airspace is referred to as an Automated Traffic Management System (ATMS) in this document.[7] It is envisioned that this ATMS will provide both strategic and tactical deconfliction services within Class X airspace. Communication and data exchange between the ATMS and AFR aircraft will be digital rather than voice-based. A digital interface will also be established between the ATMS and ATC, enabling the local ANSP to maintain a strategic role in the management of Class X airspace. Through this interface, ATC may receive surveillance data, apply airspace constraints, and receive alerts related to non-conforming flights within the Class X airspace.

For the ATMS to perform safety-critical deconfliction of aircraft in Class X airspace, it will require access to surveillance data with high integrity, high availability, and low latency. Meeting these requirements will require independent surveillance sources, such as ground-based radar, that do not rely solely on aircraft self-reported data. Self-reported surveillance, including ADS-B, is insufficient on its own due to security and availability limitations[8] , and does not provide detection of non-cooperative aircraft. Despite these limitations, ADS-B and other potential electronic conspicuity solutions remain valuable complementary data sources. When correlated with radar, ADS-B data can be validated and used to increase the accuracy and update rate of the overall surveillance solution.

Figure 3 provides a notional illustration of the concept described.

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[6] *This notion is supported by the FAA's UAM and Info-Centric NAS ConOps, as well as SESAR's U-Space ConOps.*

[7] *Although represented here as a single entity, the ATMS may potentially be deployed as a combination of several systems. A discussion of system architecture is outside the scope of this paper.*

[8] *From a security perspective, ADS-B is known to be susceptible to spoofing and GPS jamming. From an availability standpoint, ADS-B depends on an aircraft's navigation system to generate a position solution and may also be vulnerable to spectrum congestion. These limitations have been previously identified and documented in industry standards, including RTCA DO-365 for detect-and-avoid systems.*

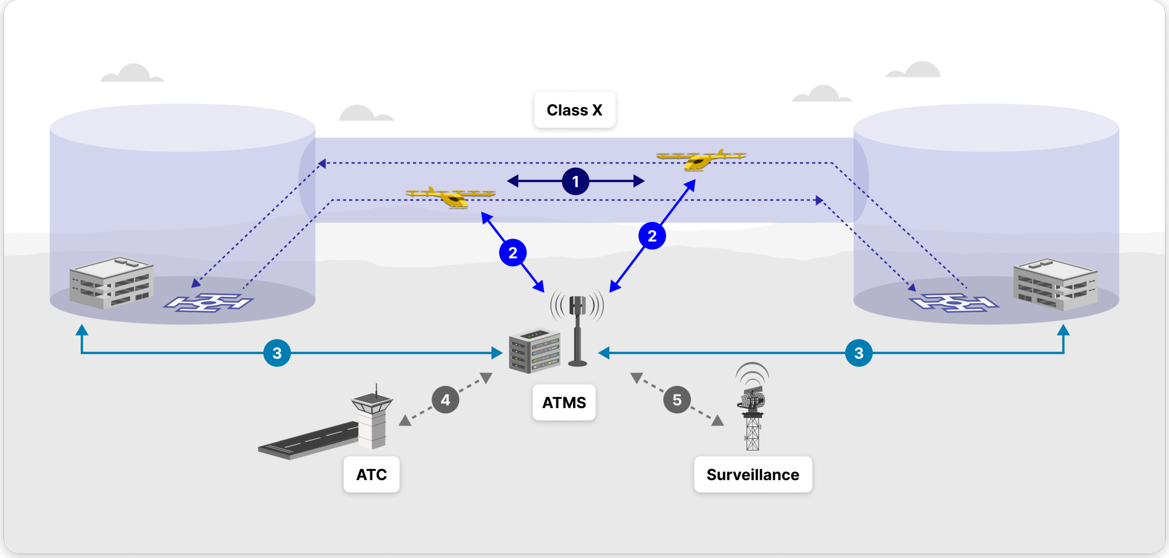

Figure 3. Notional illustration of operations in Class X airspace. (1) Denotes aircraft-to-aircraft data exchange, such as transponder interrogations and position reports for collision avoidance. (2) Denotes data exchange between the ATMS and aircraft, used to deliver strategic and tactical conflict management instructions. (3) Denotes data exchange between the ATMS and takeoff and landing facilities, which is used for demand-capacity balancing. (4) Denotes data exchange between the ATMS and ATC. (5) Denotes surveillance data received by the ATMS from independent ground-based systems.

The automation of conflict management in Class X airspace will be enabled by the following key capabilities, highlighted in Figure 3:

- **Automated Traffic Management System (ATMS):** Ground-based system responsible for providing conflict management and data services in Class X airspace.
- **Ground-Based Surveillance System (GBSS):** Ground-based surveillance system providing high-assurance surveillance data to the ATMS for traffic management in Class X airspace.
- **ATMS-Aircraft Link:** Secure, low-latency, high-availability datalink between the ATMS and AFR aircraft for the exchange of safety-critical data, alerts, and maneuver instructions.
- **ATMS-ATC Interface:** Secure, low-latency digital interface between the ATMS and the local ATC facility that enables ATC to receive information and maintain a strategic role in the management of Class X airspace.
- **Onboard Collision Avoidance System:** System onboard the aircraft that mitigates rare cases in which the ATMS is not capable of resolving a conflict. Examples include TCAS and ACAS X.

Class X airspace, shown in purple in Figure 3, will be established within existing low-altitude airspaces and will be primarily allocated to AFR aircraft.[9] It is envisioned that surrounding IFR and VFR traffic will be allowed to transit across a Class X airspace while following specific procedures.[10] In cases where redesignating portions of airspace as Class X airspace is not desirable, a UAM route structure may continue to exist partially inside traditional airspace classes (Figure 4). UAM aircraft transiting from Class X airspace into conventional controlled airspace would be expected to establish communication with ATC, and the ATMS would support traffic flow metering at the handoff waypoint. During these airspace transitions, UAM aircraft will continue to operate under AFR and will not switch flight rules.

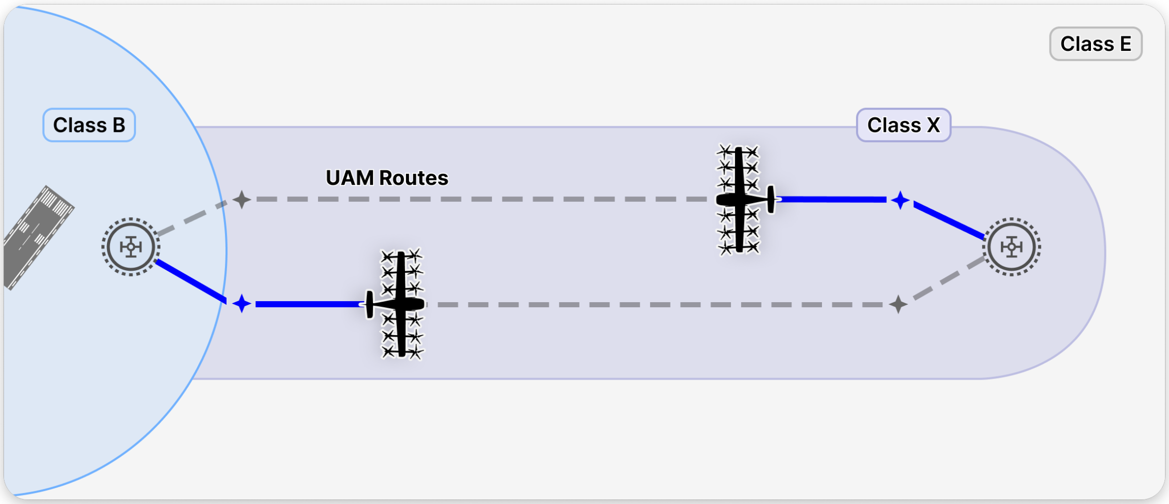

Figure 4: Notional example of a scenario where UAM routes exist partially inside of a Class B airspace and partially inside Class X airspace.

A key objective in designing Class X airspace will be to minimize airspace usage and potential disruptions to traditional traffic, while ensuring adequate spacing between UAM routes and sufficient volume to support tactical deconfliction maneuvers. Minimum route spacing within Class X airspace will be informed by studies of collision risk between UAM aircraft operating on RNP routes, similar to analyses previously used to establish minimum spacing between closely spaced approach procedures.

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[9] *It is proposed that parts of existing airspaces would be redesignated as Class X airspace.*

[10] *This permeability of Class X airspace is intended to accommodate general aviation, emergency medical services (EMS), and other non-routine operations.*

The overall dimensions of Class X airspace may also be influenced by a minimum required separation from airspace boundaries.[11] A notional illustration of the basic geometric parameters shaping Class X airspace is shown in Figure 5.

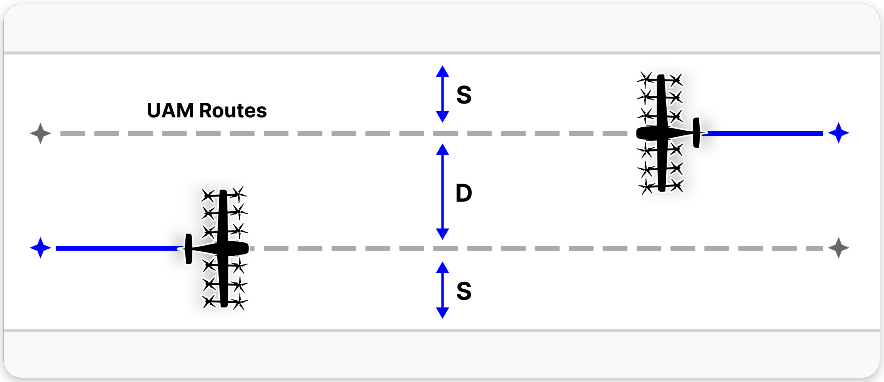

Figure 5: Notional design of Class X airspace. 'D' represents the spacing between parallel UAM routes, driven by the performance of the conflict management solution when resolving conflicts that arise from lateral course deviations. 'S' represents the spacing between UAM routes and the boundary of Class X airspace, which must account for separation from non-UAM traffic and provide buffer volume for tactical deconfliction maneuvers by UAM aircraft.

The next section discusses the key functions performed by the ATMS to organize and separate traffic in Class X airspace.

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[11] *In the United States, a minimum distance of 1.5 nautical miles is typically applied between published routes and airspace sector boundaries to ensure adequate radar separation between aircraft in adjacent sectors (FAA JO 7110.65BB § 5-5-10).*

4.

Automating Conflict Management in Class X Airspace

The International Civil Aviation Organization (ICAO) defines conflict management as a process that “limits, to an acceptable level, the risk of collision between aircraft” (ICAO Doc 9854). This process encompasses the actions taken to both organize and separate air traffic. To date, airspace conflict management has relied primarily on human-to-human coordination, such as air traffic controllers issuing separation instructions to pilots using voice-based communications. Under AFR operations, conflict management functions are expected to be highly automated, reducing the need for direct human coordination and involvement. **The automation of conflict management is a fundamental enabler of AFR.**

Conflict management is a layered process that begins prior to departure and continues throughout the flight. The proposed AFR conflict management framework builds on the framework outlined in ICAO Doc 9854 and adapts it into four primary processes that reflect a typical UAM mission profile. Together, these processes are intended to keep aircraft operating within Class X airspace efficiently organized and safely separated from one another, as well as from traffic that may cross Class X airspace. Each process aligns with a distinct time horizon along the timeline of a conflict, as illustrated in Figure 6 and described below.

Figure 6: Conflict Management framework proposed for UAM operations in Class X airspace.

- **Strategic Conflict Management:** Process of conditioning the overall traffic flow to make in-flight separation manageable. It is implemented through airspace design and demand-capacity balancing. Actions are taken while the aircraft is still on the ground and before it leaves its parking stand. The objective of strategic conflict management is to reduce, but not eliminate, the possibility of in-flight conflicts.
- **Pre-Tactical Conflict Management:** Process of implementing adjustments to an aircraft's operational intent after it has left its parking stand but before takeoff, in response to real-time flow management constraints. It is primarily achieved through departure metering (i.e., adjusting takeoff times) but may also include modifications to the aircraft's route and/or cruise speed.
- **Tactical Conflict Management:** Process of maintaining an orderly traffic flow and ensuring minimum separation between aircraft in flight. It is achieved through in-flight changes to aircraft trajectory and/or speed. Actions are taken tens of seconds to several minutes before a potential conflict.
- **Collision Avoidance:** Process of mitigating the risk of collision when tactical conflict management measures have not prevented a conflict. It relies on resolution advisories generated by an onboard collision avoidance system. Actions are taken seconds before a potential collision.

The sections below further describe how these processes will be automated in Class X airspace using a combination of ground-based and onboard systems.

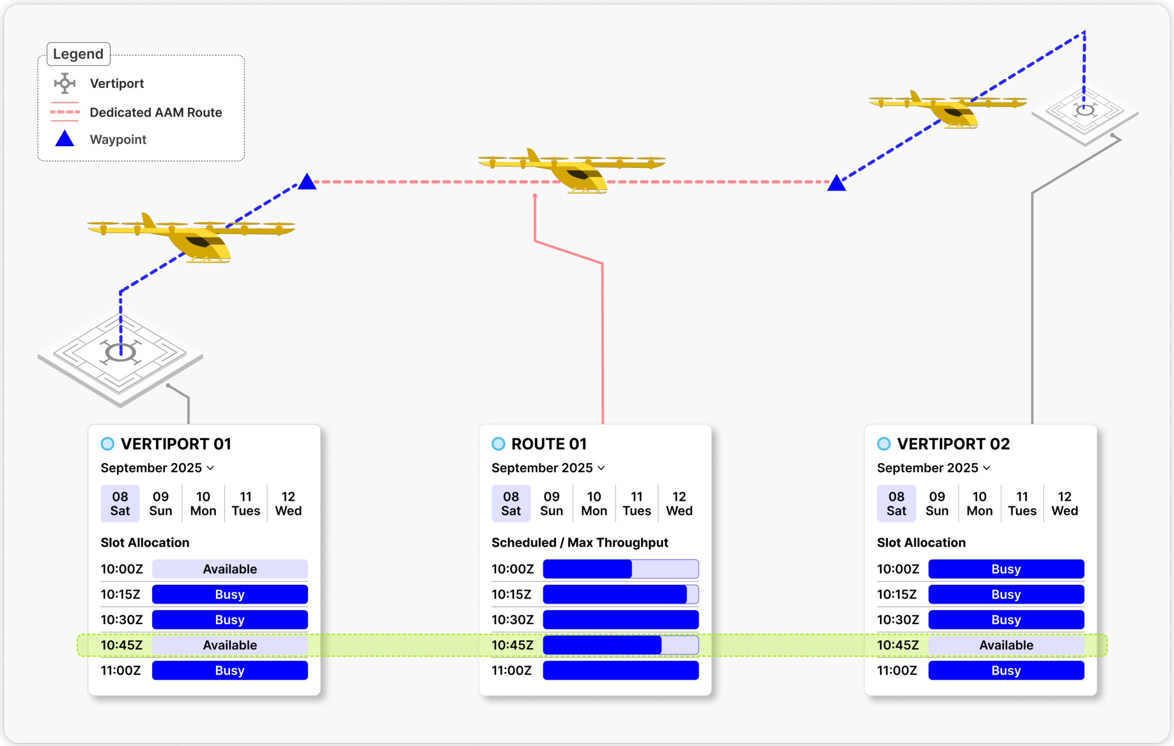
4.1

STRATEGIC CONFLICT MANAGEMENT

As flights are planned in Class X airspace, the ATMS will efficiently balance resource utilization, reserve takeoff and landing slots, and verify that planned flights adhere to the operational rules of the airspace.

By coordinating slot reservations and flight approvals, the ATMS will ensure that operations in Class X airspace remain highly organized. Combined with the short duration of urban flights, this approach will make UAM operations in Class X airspace highly predictable, requiring little to no adjustment to flight trajectories once airborne under normal conditions.

Demand-Capacity Balancing: To ensure flights are efficiently scheduled, the ATMS will enforce demand-capacity balancing (DCB) principles as AFR flights are planned. During this process, the available capacity of both ground infrastructure (e.g., takeoff and landing facilities) and airspace resources (e.g., Class X airspace, routes, and waypoints) will be evaluated to determine how best to accommodate additional flights. Capacity constraints, typically expressed as the maximum number of aircraft movements permitted within a specified time window (e.g., three movements per 15-minute interval), will be communicated to the ATMS by facility (e.g., vertiport) operators and ATC[12], or established through operational agreements. The ATMS will use this information to allocate resources to upcoming flights, including precise scheduling of takeoff and landing slots that ensure efficient use of airspace and infrastructure.[13]



VERTIPORT 01

September 2025

08 Sat	09 Sun	10 Mon	11 Tues	12 Wed

Slot Allocation	
10:00Z	Available
10:15Z	Busy
10:30Z	Busy
10:45Z	Available
11:00Z	Busy

ROUTE 01

September 2025

08 Sat	09 Sun	10 Mon	11 Tues	12 Wed

Scheduled / Max Throughput	
10:00Z	
10:15Z	
10:30Z	
10:45Z	
11:00Z	

VERTIPORT 02

September 2025

08 Sat	09 Sun	10 Mon	11 Tues	12 Wed

Slot Allocation	
10:00Z	Busy
10:15Z	Busy
10:30Z	Busy
10:45Z	Available
11:00Z	Busy

Figure 7: Demand-capacity balancing will be enforced by the ATMS to produce an orderly traffic flow in Class X airspace.

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[12] *Capacity constraints communicated by ATC may include available capacity at major airports and capacity at handoff waypoints when an AFR flight is planned to transition into controlled airspace.*

[13] *While traditional DCB typically allocates resources using coarse time windows (e.g., aircraft per hour), AFR operations will rely on single-aircraft takeoff and landing slot reservations to improve the predictability of resource utilization.*

Operational Intent Validation: In addition to balancing demand and capacity within Class X airspace, the ATMS will validate operational intents before departure to ensure proposed UAM operations conform to designated routes and altitudes under the expected airspace configuration. Additional operational restrictions may also be verified at this stage, such as those related to weather or time of day. This validation process will serve a role similar to clearance delivery in conventional air traffic management.[14]

4.2

PRE-TACTICAL CONFLICT MANAGEMENT

In Class X airspace, the ATMS will manage aircraft sequencing and spacing along UAM routes, beginning with actions implemented just prior to takeoff.

Departure Metering: Once a UAM aircraft is ready for departure, the ATMS will be responsible for issuing a departure authorization. This authorization will account for required separation from other inbound and outbound aircraft at the departure vertiport, as well as sequencing and spacing constraints along the planned route and at the arrival vertiport. For example, when multiple UAM routes converge onto a common approach segment, the ATMS will meter departures to ensure a properly sequenced arrival flow at the merge point (Figure 8).

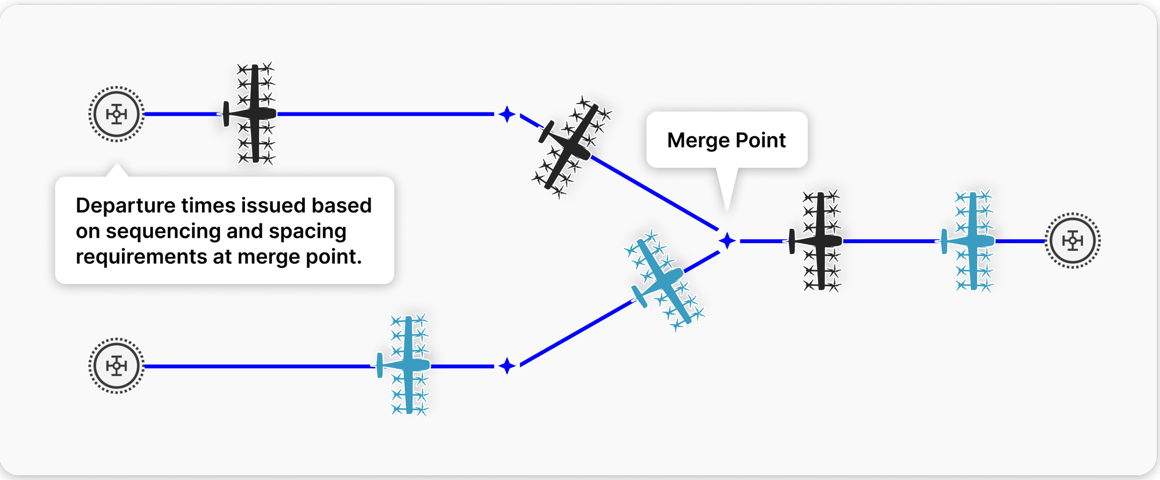

Figure 8: The ATMS will issue departure authorizations based not only on the need for separation from inbound and outbound aircraft at the departure vertiport, but also based on sequencing and spacing objectives along the flight route.

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[14] *Changes in airspace configuration, such as those caused by a Class B airport changing runway configuration, may cause different AFR routes and Class X volumes to become active.*

If a flight is expected to land at a vertiport located in ATC-controlled airspace (e.g., a Class B airport), the ATMS will use data from the ANSP to meter departures in support of ATC traffic flow objectives. For instance, when a UAM approach occurs as a simultaneous dependent approach[15] alongside an ILS approach for conventional jet traffic into a Class B airport, the ATMS may meter UAM departures from Class X airspace to support ATC's application of radar separation standards (Figure 9).

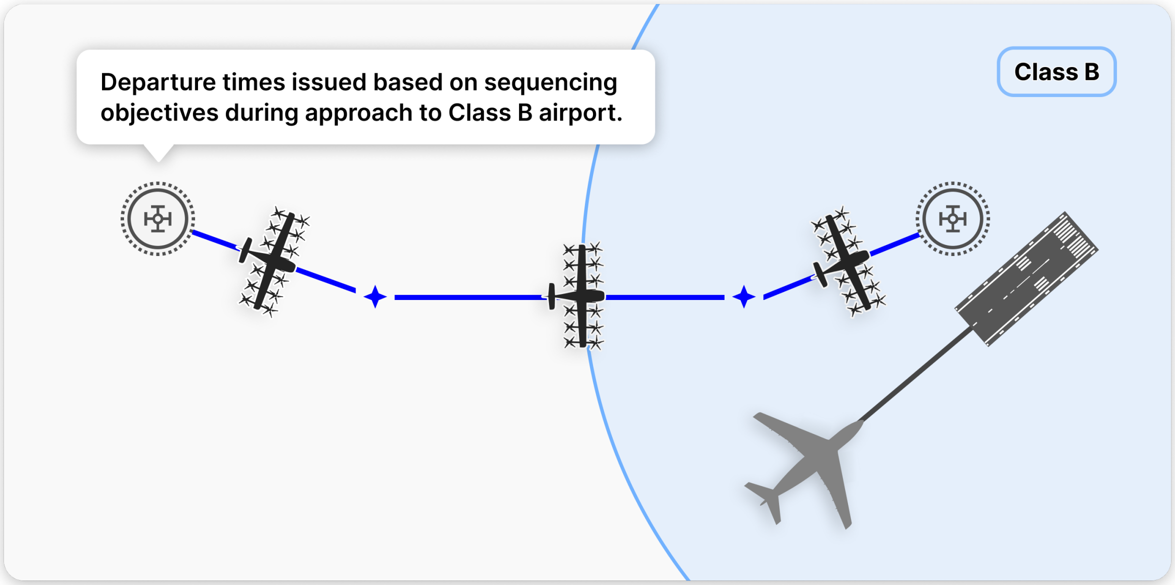

Figure 9: When departing from a vertiport located in Class X airspace and landing at a Class B airport, UAM aircraft will be metered by the ATMS based on sequencing objectives of the ATC in charge of the Class B.

For short UAM flights (i.e., less than 30 nautical miles), departure metering is proposed as the primary method for sequencing and spacing flights in Class X airspace. Changes made to an aircraft's departure time by the departure metering function will additionally be validated by the demand-capacity balancing and operational intent validation functions discussed in Section 4.1.

4.3

TACTICAL CONFLICT MANAGEMENT

During flight, the ATMS may issue maneuver instructions to keep the flow of traffic organized and to maintain safe separation between aircraft. Tactical conflict management functions can thus be grouped into: (i) flow management, which focuses on overall traffic organization, and
(ii) separation provision, which enforces a minimum distance between aircraft.

Flow Management

Interval Management: Once airborne, aircraft spacing and estimated arrival times at downstream route waypoints may be adjusted through cruise speed changes. This process, known as *interval management*, will be managed by the ATMS and executed in response to minor uncertainties or disturbances in the traffic flow. As part of their approved flight intent, UAM aircraft operating in Class X airspace may specify a range of in-flight speeds they can maintain, enabling the ATMS to issue speed changes while considering individual aircraft performance.

Dynamic Rerouting: In some scenarios, larger traffic flow adjustments may be required that involve modifying an aircraft's trajectory. Examples include a missed approach that requires re-sequencing an aircraft into the arrival flow, a diversion to an alternate destination within Class X airspace, or a response to a procedural crossing of the Class X airspace by surrounding traffic.[16] In these cases, the ATMS will manage in-flight changes to approved operational intents through a *dynamic rerouting* function.

For instance, following a missed approach at a vertiport, the ATMS will issue instructions for the aircraft to rejoin the approach after identifying available "slots" in the current arrival sequence (Figure 10). To ensure these trajectory adjustments remain within Class X airspace, the design of the airspace must provide sufficient volume to accommodate such maneuvers.

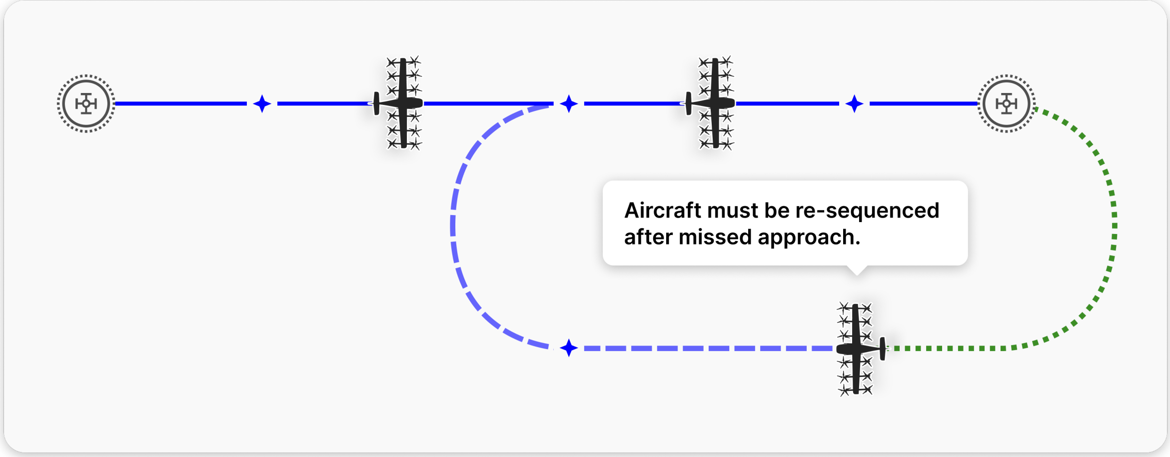

Figure 10: Notional illustration of an example scenario in which dynamic rerouting instructions are provided by the ATMS.

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[16] *A procedural crossing is defined as one in which the crossing aircraft follows a pre-determined procedure, such as announcing its intent to cross Class X airspace ahead of time and/or using specific crossing routes.*

The need to tactically reorganize traffic under certain conditions may favor a centralized flow management function, as decentralized decision-making would likely add latency and coordination complexity in situations where predictable behavior and fast response times are highly desirable.[17]

Separation Provision

A minimum separation distance between aircraft in Class X airspace will be maintained by the ATMS through its separation provision function. Given that AFR routes will be designed to be spatially deconflicted, it follows that two basic types of in-flight conflicts can exist in Class X airspace:

1. Conflicts involving non-conforming AFR aircraft, caused by an AFR aircraft deviating from its assigned route or schedule.
2. Conflicts involving non-AFR intruder aircraft, caused by non-AFR aircraft unexpectedly entering Class X airspace.

Conflicts due to deviating UAM aircraft

During operations, the ATMS will perform continuous conformance monitoring of all airborne AFR traffic against lateral, vertical, and along-track conformance thresholds. Each UAM route will have pre-specified conformance thresholds, and any deviation exceeding these limits will be flagged as a non-conformance condition. For example, a UAM route using an RNP 0.1 NavSpec may have a lateral conformance threshold of 0.1 nautical mile, meaning an aircraft would be considered non-conforming if it deviates laterally from its assigned route by more than 0.1 nautical mile.

Upon detecting a non-conformance condition, the ATMS will:

1. Alert the non-conforming aircraft of its non-conformance condition, alert ATC (if applicable[18]), and provide the non-conforming aircraft with instructions to correct its flight trajectory (Figure 11).

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[17] *In contrast, decentralized and federated architectures likely remain suitable for strategic conflict management, since fast response times are less critical prior to takeoff.*

[18] *This is done in case the deviating aircraft may present a hazard to the surrounding airspace.*

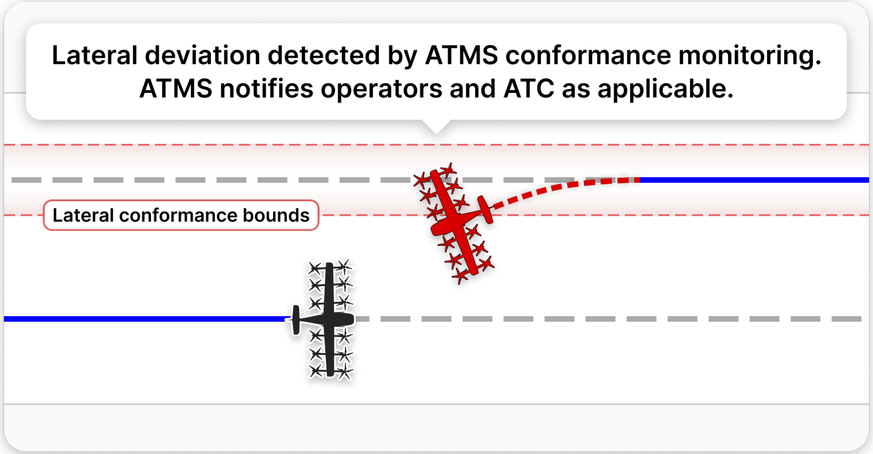

Figure 11: Notional illustration of non-conformance condition due to a lateral course deviation.

2. Alert any aircraft that may be endangered by the non-conforming aircraft and, if necessary, issue maneuver instructions to those aircraft to resolve the conflict (Figure 12).

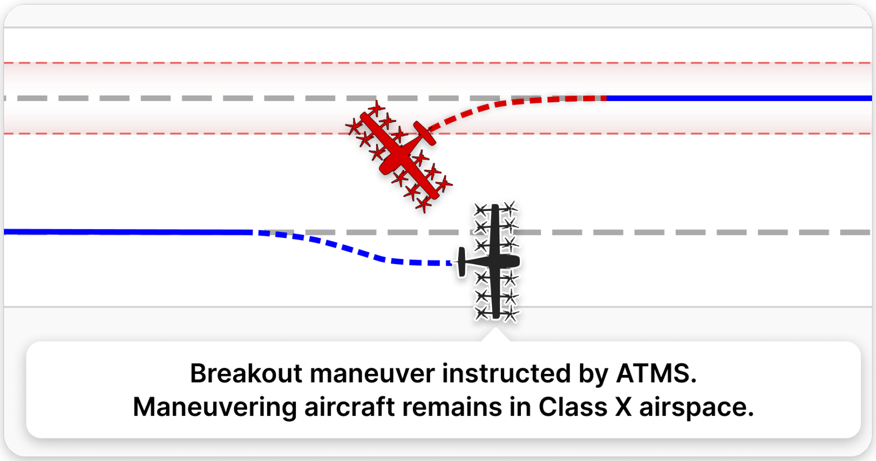

Figure 12: Notional illustration of a deconflicting maneuver instruction issued by the ATMS.

The procedure described above emulates breakout maneuvers used in current IFR approaches to closely spaced parallel runways when an aircraft deviates from its final approach course. In the AFR context, however, automation is expected to enable faster detection of non-conforming aircraft and quicker responses. **This faster response to course deviations between closely spaced routes is a key mechanism for enabling closer separation between UAM routes in the future.**[19]

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[19] *In surveilled airspace, the separator's response time to a course deviation is a key factor in determining the required spacing between instrument routes and procedures.*

After the non-conformance condition and associated conflicts are resolved, any residual traffic flow disruptions that still exist will be handled by the dynamic rerouting and interval management functions described earlier.

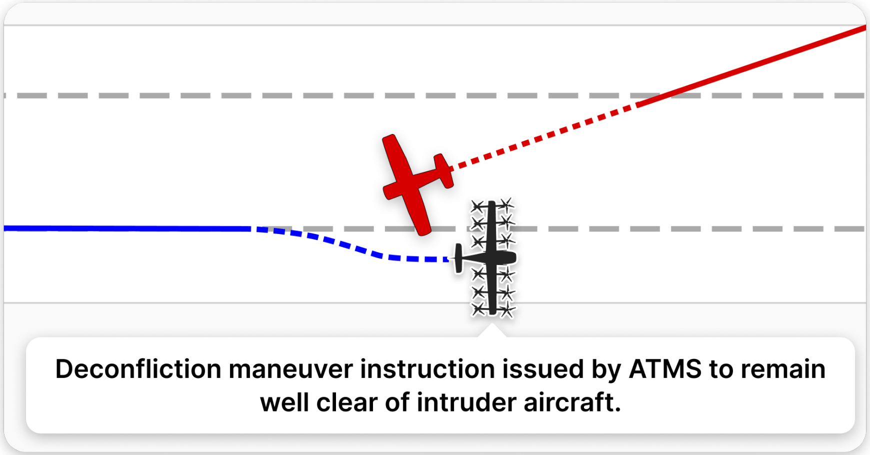
Conflicts due to intruder aircraft

During operations in Class X airspace, AFR aircraft may encounter non-cooperative traffic that unexpectedly enters the airspace. To resolve potential conflicts with these intruders, the ATMS will provide traffic alerts and maneuver instructions to at-risk AFR aircraft. Since the exact intent of an intruding aircraft cannot be assumed, these instructions are expected to follow a logic similar to that used by detect-and-avoid (DAA) systems, which also operate without relying on traffic intent information.

However, this use case requires the ATMS to address additional objectives that extend beyond the scope of existing DAA capabilities:

- Maneuvers should remain within the boundaries of Class X airspace, when possible.
- Maneuvers should avoid forcing other UAM aircraft to modify their trajectories, when possible.
- Maneuvers should minimize disruptions to the overall traffic flow within Class X airspace.
- Maneuvers should conclude with the aircraft rejoining its planned route.

Put another way, AFR separation provision for the intruder use case may be viewed as an extension of the DAA remain-well-clear logic, incorporating contextual information about the Class X airspace, its route structure, and the traffic present in it.



Deconfliction maneuver instruction issued by ATMS to remain well clear of intruder aircraft.

Figure 13: Notional illustration of deconfliction maneuvers issued by ATMS to clear a conflict with an intruder aircraft.

4.4

COLLISION AVOIDANCE

The collision avoidance function, often described as the "last layer of defense" in ICAO's conflict management framework, must operate independently from other conflict management functions and requires low system latency due to the short time horizon for collision avoidance actions. As a result, it is considered desirable for the collision avoidance function to remain onboard the aircraft rather than be provided by a ground-based system.

Currently, TCAS is the system commonly used by commercial passenger aircraft for collision avoidance. For UAM operations in Class X airspace, tailored systems such as ACAS Xr are expected to replace TCAS while continuing to rely on transponder interrogations and ADS-B broadcasts for surveillance inputs.

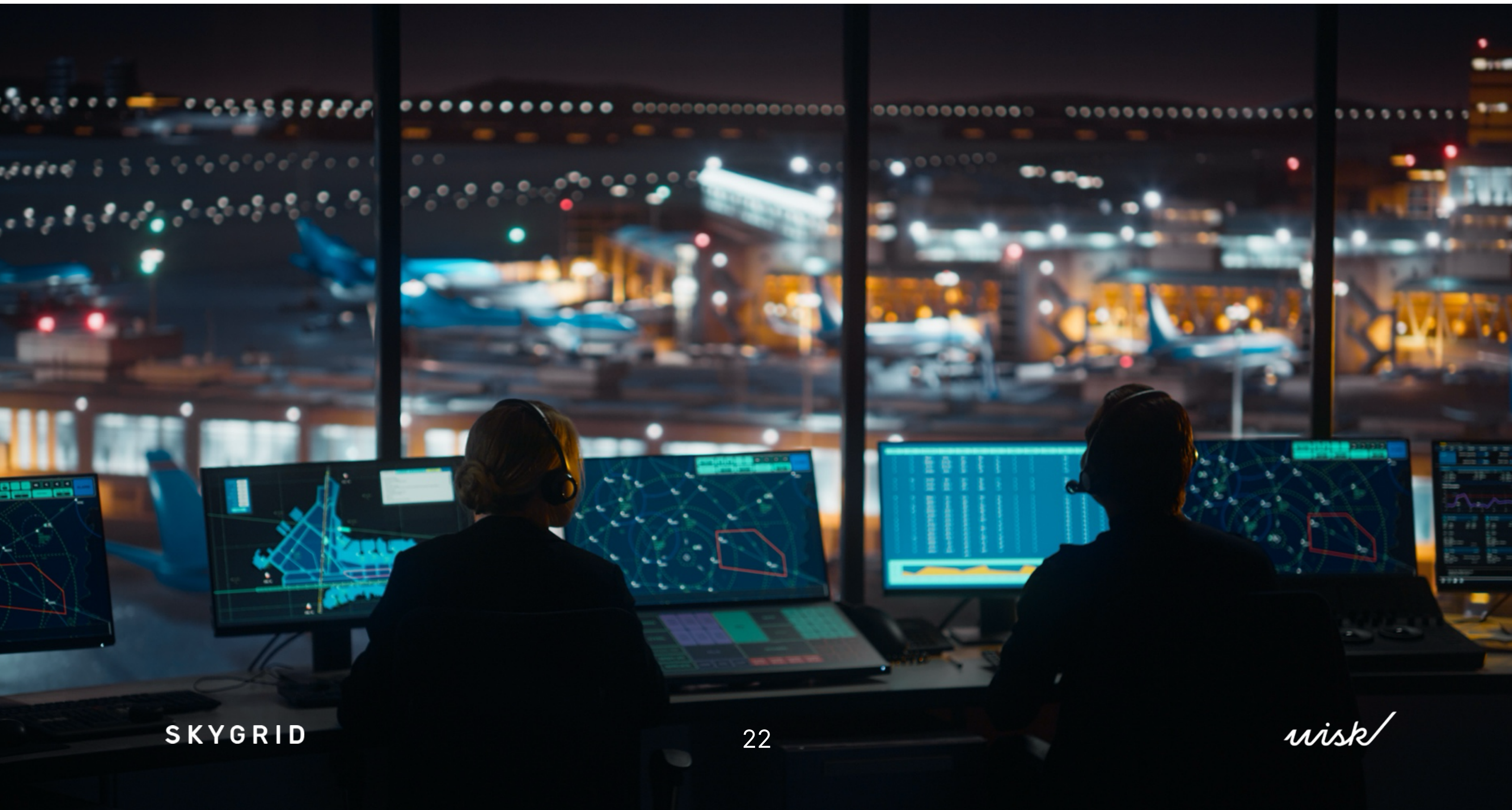
Further work will be needed to assess the interoperability of onboard collision avoidance and DAA systems with the ATMS separation provision function described in the previous section, as well as to evaluate the expected frequency of nuisance collision avoidance alerts under different AFR route geometries.

5.

Additional ATMS Functions

In addition to the conflict management functions described in Section 4, the ATMS will provide additional data and coordination services, including:

- **Digital Operating Picture:** The ATMS will maintain and distribute a real-time digital model of the operating environment to support collaborative decision-making (CDM) by airspace users and facility operators. This digital operating picture will include surveillance data for active flights, approved operational intents, weather conditions, operational constraints, and disruption alerts. It will be shared with multiple stakeholders, including aircraft operators, facility operators, and ATC.
- **Disruption Management:** In addition to providing single-flight dynamic rerouting as described in Section 4.3, the ATMS will also be capable of managing multi-aircraft disruption events, such as a vertiport closure affecting multiple flights. In such cases, the ATMS may issue ground holds, reassign aircraft to alternate landing sites, and issue updated operational intents to affected operators.



6.

Interfaces with Air Traffic Control

As illustrated in Figure 3, the ATMS will interface digitally with the local air traffic system and ATC to exchange data, receive ATC inputs, and communicate relevant operational events. Rather than removing ATC from the loop, Class X airspace is intended to enable controllers to manage UAM operations in a more strategic capacity, without the need to provide routine tactical instructions to individual aircraft. Functions served by ATC will include managing the configuration of Class X airspace and implementing traffic management initiatives (TMIs) as needed to align with the operational constraints of the surrounding controlled airspace.

Information received by the ATMS will include (but is not limited to):

- Surrounding airspace configuration, which may determine the configuration of the Class X airspace and the active routes within it.
- Constraints imposed by ATC on the capacity or availability of the Class X airspace.
- Demand and capacity information for airspace and ground resources located outside of Class X airspace.
- Metering constraints (e.g., miles-in-trail) at handoff waypoints along the boundary of Class X airspace, which the ATMS must observe when handing off traffic to ATC.
- Handoff and point-out messages related to traffic entering or transiting Class X airspace from controlled airspace.

Information sent by the ATMS will include (but is not limited to):

- Surveillance information for aircraft operating within and in the vicinity of Class X airspace.
- Approved and active AFR operational intents.
- Alerts of non-conforming aircraft within Class X airspace.
- Alerts of conflicts within Class X airspace being resolved by the ATMS.
- Handoff and point-out messages related to traffic entering controlled airspace from Class X airspace.

New interfaces will be developed to support this data exchange with traditional ANSP systems. Likewise, further work will be needed to clarify the roles and responsibilities of air traffic controllers interacting with an ATMS.

7.

Conclusion

This white paper introduced a concept for a new operating mode that leverages traffic management automation to support more scalable low-altitude UAM operations. As the UAM industry seeks to conduct low-altitude missions at tempos comparable to those observed today at major airports, new technologies and procedures will be required to manage traffic safely and efficiently without overwhelming the current air traffic system. The paper proposed that the scalability of UAM operations can be significantly improved with three key elements: (i) new traffic management automation, (ii) a new airspace structure in which traffic management is automated, and (iii) new flight rules termed Automated Flight Rules (AFR). Taken together, these elements are expected to enable levels of UAM scalability that are not achievable within the current airspace system and are therefore viewed as essential for the long-term commercial success of the UAM industry.

In the future, traffic management automation developed to support UAM operations may also evolve to benefit other airspace users, paving the way for the air traffic system to accommodate increasingly automated operations across the entire airspace system. SkyGrid and Wisk, alongside Boeing, invite ICAO, civil aviation authorities, and ANSPs worldwide to collaborate with industry in validating and refining the proposed concept. The final sections below offer some potential directions for future work.

7.1

DEVELOPMENT ROADMAP

Below are proposed development milestones that could help guide the continued maturation and refinement of the AFR concept as applied to UAM operations in Class X airspace. Rather than an exhaustive roadmap, this list is offered as a starting point for future work and discussion among relevant stakeholders.

Concept maturation

- Maturation of AFR conflict management framework and demonstration of safety, efficiency, and capacity objectives.
- Development of procedures for coordination between ATMS and ATC, including traffic handoff and metering at handoff waypoints.
- Validation and refinement of Class X airspace design and entry requirements.
- Identification of realistic opportunities for rollout of Class X airspace in urban environments.
- Human-in-the-loop simulations using realistic airspace models to validate benefits and assess impacts on surrounding airspace and air traffic controller workload.

System development

- Development of a high-assurance ground system capable of performing automated traffic management functions.
- Development of a ground-based surveillance system capable of supporting automated traffic management.
- Definition of new interfaces for data exchange between ATMS and traditional ANSP systems.

Rulemaking and standards

- Development of formal flight rules (AFR) that define operational procedures, required equipment, and operational approval processes for operators of highly automated aircraft.
- Development of a new class of airspace in which conflict management functions can be allocated to automated systems.

- Identification of possible certification paths for an ATMS and development of associated performance standards.
- Development of performance standards for an ATMS-to-aircraft datalink.
- Development of performance standards for automated conflict management functions, including strategic, pre-tactical and tactical conflict management.
- New industry standards to define the process and rules by which vertiport slots can be reserved by UAM operators.

Deployment

- Near-term:
  - Deploy strategic and pre-tactical conflict management automation (i.e., demand-capacity balancing and departure metering) for initial UAM flights under VFR and IFR, aiming to reduce controller workload and pilot-controller interactions.
  - Enable automated departure authorizations and IFR releases from vertiports.
  - Begin introducing lower-complexity tactical conflict management automation, such as interval management.
- Mid-term:
  - Begin introducing new airspace structures (i.e., Class X) in lower-complexity environments.
  - Exercise complete ATMS functionality at low operational tempos in Class X airspace, initially relying on a higher level of human supervision.
- Long-term:
  - Expand Class X airspace into higher-complexity environments.
  - Exercise complete ATMS functionality with little to no human supervision, and enable coordinated transitions between Class X airspace and ATC-controlled airspace.
  - Operational tempo allowed to increase gradually.

7.2

FUTURE WORK

SkyGrid and Wisk invite industry, government, and academic partners to collaborate on key technical areas that will advance the development of core elements of the proposed AFR concept. The following list highlights high-value work areas:

- **Surveillance Requirements:** Define the system requirements that an independent ground surveillance system must meet to support separation provision in Class X airspace without human involvement or intervention.
- **Safety Assessment:** Conduct risk assessments and identify hazard classifications for ATMS functions, including automated strategic, pre-tactical, and tactical conflict management.
- **Crossing Procedures:** Specify procedures and ATMS behavior for managing VFR and IFR traffic crossing Class X airspace.
- **Handoff Procedures:** Define handoff procedures and ATMS behavior for AFR aircraft transiting between Class X and controlled airspace.
- **Navigation Specifications:** Develop NavSpecs for new simultaneous independent approach procedures for UAM, by leveraging concepts such as Established-on-RNP (EoR) and Multiple Airport Route Separation (MARS).
- **Diversion Procedures:** Establish diversion procedures for UAM aircraft operating in Class X airspace.
- **Detect-and-Avoid Standards:** Expand DAA standards to support closely spaced operations and ensure interoperability with ATMS in Class X airspace.

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