Urban Air Mobility Airspace Integration Concepts

Operational Concepts and Exploration Appoaches

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Introduction to UAM Concept

Urban Air Mobility (UAM) is an industry term used to describe a system that enables on-demand, highly automated, passenger- or cargo-carrying air transportation services. The industry vision involves leveraging new vehicle designs and system technologies, developing new airspace management constructs and operational procedures, and embracing the sharing and services economy to enable a new transportation service network.

Aircraft manufacturers and service providers expect to use electric vertical takeoff and landing (eVTOL) technologies to enable runway-independent operations. They also expect to operate with very high degrees of automation, up to and including fully self-piloted aircraft[1]. Most operators envision an on-demand service, enabling growth up to 100s or 1,000s of simultaneous operations around a metropolitan area at altitudes up to 5,000 feet and speeds up to 150 knots. These aircraft would carry cargo or 1-5 passengers on short-range trips (e.g. less than 100 km) [1].

These operational characteristics will prevent an immediate deployment of full-scale UAM operations since existing airspace procedures, regulations, policies, and structures will not necessarily accommodate the envisioned operations. As an example, without an on-board pilot, compliance with visual flight rules and see and avoid requirements will not be feasible. Most proponents propose operating at a limited scale, some even proposing to begin with pilots in the aircraft much like current day helicopter operations, until the necessary constructs evolve to enable high-density self-piloted operations. This paper explores the challenges of integrating highly automated UAM operations into the National Airspace System (NAS). It then presents some operational concepts that could enable safe integration of UAM into the NAS. The UAM industry is beginning to explore and socialize ideas around UAM integration challenges. [2] [3] [4]. This paper offers future integration principles and presents a postulated operational framework that utilizes specific aviation concepts to enable safe and efficient airspace integration. The described concepts are not intended to define the exact solution space for future operations. However, this framework can serve as a starting point for concept evaluations, which then inform the development of systems and solutions that enable initial operations.

Challenges Under Today's Constructs

In today's operations, two flight rules constructs are used to mitigate risks of collision and ensure a smooth flow of traffic: Visual Flight Rules (VFR) and Instrument Flight Rules (IFR).

With VFR, the pilot must be able to operate the aircraft both with visual reference to the ground, and to visually avoid terrain, obstructions and other aircraft. The concept of Visual Meteorological Conditions (VMC) is used to quantify the cloud clearance, ceiling, and visibility requirements needed for a pilot to see the ground, obstructions, and other aircraft. The key to using VFR is having a human pilot onboard to use their eyes, brain, knowledge, experience, and training to mitigate risks of collision and inadvertent entry into unsafe meteorological situations.

[1] Many in the UAM industry are using the term "self-piloted", to refer to an aircraft that does not have an on-board pilot or a remote pilot who is actively engaged in the individual flight. The aircraft is essentially piloting itself via automation. Most proponents envision a human will likely be remotely supervising potentially large numbers of simultaneous operations.

Under operating conditions where the pilot cannot safely operate as VFR using visual references, the pilot conducts flight under IFR using other mechanisms to help mitigate risks of collision. Since visual reference may not be adequate, cockpit instruments are used to support navigation. However, as in VFR operations, responsibility for aircraft avoidance remains with the pilot, though this function is largely managed by Air Traffic Control (ATC) through separation services. The pilot must file a flight plan with ATC and will receive and must follow instructions provided by ATC to maintain separation (unless flight is within Class G airspace). Since IFR aircraft are sharing telemetry (squawking) and are communicating on voice channels (talking), ATC has increased situational awareness of other traffic that the IFR aircraft pilot may not have (e.g., due to lack of a visual reference when in clouds)[2]. The key to using IFR is having ATC provide separation services to aid a pilot that may not be able to see other traffic and mitigate risk of collision on their own.

Airspace is divided into six categories, with differing operational requirements and levels of ATC service provision. Airspace classes include Class A, B, C, D, E, and G, with Class A being the most restrictive and Class G being the least restrictive in terms of requirements. In some airspace (e.g., Class B), separation services are provided regardless of whether the flight is IFR or VFR because the traffic may be too dense to self-separate. In other more lightly travelled airspace (e.g., Class G), separation services are not provided, and the airspace is considered "uncontrolled".

Unmanned Aircraft Systems (UAS) Traffic Management (UTM) is another construct currently under development for use by UAS operating at low altitudes (e.g. below 400 feet). UTM provides a set of traffic management services via a federated group of UTM Service Suppliers (USS), comparable to traditional ATC services provided to IFR and VFR aircraft.

Current flight rules (VFR, IFR), and UTM services impose the following limitations on envisioned UAM aircraft:

- Without a trained human pilot onboard the UAM aircraft, the flight will not be able to meet 14 Code of Federal Regulations (CFR) Part 91 using VFR or IFR, because no human entity would be seeing, avoiding, and following right of way rules.
- If the UAM automation is responsible for navigation, the automation will not be able to reliably "listen" and respond to instructions provided by ATC voice.
- At the expected volume of UAM operations, the standard separation distance (typically 3 NM) provided by ATC separation services will be too large to make envisioned operations viable.
- At the expected volume of UAM operations, ATC will not be able to reliably manage and provide ATC services to such a large scale of traffic.
- Since UAM operations are expected to occur above 400 feet, the current scope of UTM services would not be applicable.
- UAM aircraft operating below 400 feet may not be able to leverage some existing UTM services, since the service reliability designed for small UAS operations may need to be modified to meet the safety requirements for provision to passenger carrying UAM.

[2] In some regions of Class D airspace where aircraft are not required to equip with a transponder, ATC may not have a "full picture" of the traffic situation. Oftentimes, procedural mechanisms such as specified departure times are used to mitigate this reduced situational awareness.

Airspace Integration Framework

Integrating autonomous systems into the existing National Airspace System (NAS) is challenging but not impossible. The following mechanisms can enable airspace integration without requiring long lead-time changes such as new rulemaking or FAA capability development.

- Utilizing existing procedural constructs,
- Creating additional decision support services, and
- Allowing for flexible understanding of the intent of existing regulatory structures

These mechanisms can enable initial UAM operations to integrate safely and efficiently into the NAS without significant adverse impacts to existing operators and traffic management providers.

While other more significant changes to the design of the NAS may facilitate better flexibility of future, more mature autonomous operations, these changes are not discussed in detail in this framework. Examples of significant changes include redefining airspace classes and integrating manned and unmanned traffic into a common traffic management system. Exploratory research should begin to identify the scope of solutions that involve major changes to the NAS, however rulemaking and government investments in these major changes should wait until a common vision for the future is agreed upon.

Basic Principles for UAM Airspace Integration

The following principles guided the development of potential operational concepts to enable UAM airspace integration:

- Legacy IFR and VFR traffic should operate under the same rules as they do today.
- Minimal additional requirements should be imposed on existing ATC services provided today (any additional requirements are mostly related to off-nominal situations).
- Procedures for UAM operators should provide flexibility to address the needs of a given airspace, and scalability to enable increasing operational tempo.
- Equitable rules and airspace access should be established that maximize routing preference for both legacy operators and UAM operators.

Proposed Operational Concept Components to Enable UAM Airspace Integration

Based on the challenges of today's constructs, and the principles for future integration, the following section proposes a set of operational concept components that when combined can help enable effective integration of automated UAM operators into the NAS with minimal changes to legacy operations. Many questions arise from these concepts regarding topics such as roles, responsibilities, interfaces, and infrastructure. Each of the four main concept components will be explored in more detail below. Under each of the main concept components, there are a set of boxed bullet points which identify open questions and considerations for future research and analysis.

The following are the four main concept components which are discussed in more detail in this paper:

1. Augmented Visual Flight Rules
2. Dynamic Delegated Corridors
3. Automated Decision Support Services
4. Performance-Based Operations

Augmented Visual Flight Rules

Augmented VFR is a concept that enables UAM aircraft to operate just like piloted aircraft operate today using VFR. Augmented VFR requires an update to 14 CFR Part 91.113 such that see and avoid can be achieved through a functionally equivalent sense and avoid capability leveraging technology in a fully automated manner (i.e., without the pilot in the loop[3]). In other words, the intent of Part 91 remains the same, however the original mechanism (human eyes and brain) can now be replaced with a certified industry-developed capability that achieves the same intent. Certified systems would manage safe separation and avoidance maneuvers without needed input from a pilot, however monitoring and override functions may remain. This rules update may specify a different set of weather minimums (i.e. Augmented VMC) for certified equipment than current definitions of VMC used by piloted aircraft today. However, the rules update would not be expected to change the right of way rules. An external observer watching an aircraft's flight movement and avoidance decisions should not be able to determine if the aircraft had a human pilot or was using certified augmented VFR equipment. The sense and avoid capability may simply be a self-contained system onboard the aircraft or may be a system that leverages input from distributed systems including components on the ground (e.g., a shared radar surveillance network that shares traffic situation data suitable for the intended function with airborne aircraft). These systems would be built to industry consensus performance standards, certified by the FAA, and meet the intent of visual flight rules as currently defined in Part 91[4]. The technology that enables the "sense and avoid" function associated with Augmented VFR will be referred to as Detect and Avoid (DAA) for the purposes of this paper.

Today, in some airspace, VFR flights may fly through specially designed corridors, often referred to as *VFR corridors* and *VFR flyways*. VFR corridors enable VFR traffic to fly within controlled airspace (typically Classes B, C, and D) without requiring communications with ATC.[5] VFR flyways are general flight paths not defined as a specific course, that are used to plan flight into, out of, through or near complex terminal airspace to avoid Class B airspace [5].[6] These routes are often designed with specific local procedures, such as designated altitude maximums or transmission on certain frequencies. Augmented VFR equipment will need to be designed to meet all established local procedures for these flight corridors. This might include use of automated voice callouts to indicate current position, or intentions upon leaving the corridor.

Today's VFR corridors and VFR flyways are designed such that ATC does not have to worry about steering IFR aircraft away from the corridor, because the corridor is not placed near typical instrument procedures. In other words, corridor locations and procedures are designed so it would be very unlikely that ATC would need to provide services to VFR flights in the corridor. The next section presents a future concept for an additional type of corridor available for automated aircraft.

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[3] A pilot-in-the-loop system is a system where a human must interact with the system for it to be able to perform or control actions. In this case there is no need for any human action to ensure successful execution of a sense and avoid capability.

[4] Since rule changes can take many years, initial operations may occur under operational waivers. This would provide a near-term solution.

[5] These corridors can help expedite the flow of VFR traffic rather than require them to wait for entry clearance or fly all the way around the controlled airspace.

[6] They are often used to help establish an orderly flow of traffic around busy airspace without requiring contact with ATC.

While Augmented VFR equipment will be designed to follow right of way rules established under Part 91, some very rare traffic situations may require temporarily breaking a rule (e.g., not able to alter course to the right when approaching head on) in order to achieve the safest operating condition. Today, pilot's use best judgement to determine the safest course of action when two rules may be in conflict. Tomorrow's automation decisions will need to consider best course of action during conflicting logic situations.

Discussion Items for Future Exploration:

- Future research should identify the scope of changes needed to Part 91 and other procedures to enable Augmented VFR.
- Identification of the performance standards needed for Augmented VFR Detect and Avoid equipment.
- Future research should identify impacts on ATC's decision-making sequence if additional UAM aircraft fly within an existing VFR corridor/flyway or if new corridors or flyways solely for Augmented VFR would be appropriate.
- Today's VFR corridors/flyways may not have been designed with future UAM operators in mind. Future research should consider whether current designs are sufficient to accommodate UAM aircraft with Augmented VFR equipment.
- Future studies should explore the range of procedural possibilities for existing VFR corridors/flyways and identify any unique local procedures that would be difficult to design into Augmented VFR equipment.
- Future research should explore the avoidance priorities for maintaining flight safety and meeting the intent of Part 91 with Augmented VFR equipment.
- Explore software certification frameworks and operational safety assurance frameworks for Augmented VFR functionality.

Dynamic Delegated Corridors

The Dynamic Delegated Corridors (DDCs) concept is intended to enable UAM aircraft to operate in busy airspace by defining specific corridors that enable procedural separation from conventional aircraft operating under IFR flight rules. The concept also defines a set of rules and procedures to help coordinate traffic flows within that corridor. DDCs are volumes of airspace designated for flight using an established set of procedures and rules. DDCs are similar to the notion of VFR corridors and VFR flyways, except todays VFR corridors and flyways are rather static. The status of Dynamic Delegated Corridors will vary over time, enabling them to be opened and closed depending upon environmental conditions (e.g., wind, weather), UAM traffic density/demand, airport configurations, and legacy air traffic. Their design assumes that aircraft which utilize them will be equipped with flight automation technologies that may enable different procedural mechanisms than are typically available for conventional aircraft. DDCs would also expand the set of corridors available so that UAM aircraft are not limited to the locations where VFR corridors are defined today. The following list of assumptions are used to scope the DDC concept:

- DDCs are established and designed with input from a variety of stakeholders, such as local air traffic managers, city planners, military, etc. Design criteria considers local traffic patterns, flight-deck automation capabilities, noise and environmental concerns, and other local hazards.

- DDCs use clearly defined boundaries that can be digitally communicated (as opposed to general flight regions like a VFR flyway). The exact size, shape, and applicability time that defines a DDC may change over time, hence the term dynamic. DDCs may have a standard daily transit availability schedule, however local air traffic managers have the ability to open/close the corridor as needed to ensure safety of the airspace.
- Conventional IFR and VFR traffic are not restricted from entering DDCs but during periods where UAM aircraft are actively using the DDC for Augmented VFR operations, controllers will try to avoid clearing aircraft into that DDC. Some conventional aircraft may choose to equip with technology to enable smooth integration into the DDC when operationally necessary.
- DDCs may be defined within the boundaries of Class B, C, and D airspace. ATC treats DDCs just as they treat VFR corridors (i.e. ATC does not manage traffic nor provide separation services to aircraft in the DDC).
- DDCs may also be defined within the boundaries of Class E airspace, by an automated traffic management service (discussed in the next section).
- For some DDCs, intent to fly within a DDC should be coordinated via a certified automated traffic management service (described in the next section). Depending on local DDC procedures, entry and exit from a DDC may require clearance from an automated traffic management service.
- Flight operations in a DDC occur under the flight rules established in 14 CFR Part 91 Subpart B – Flight Rules (or any future updates to those rules). Local procedures may enable very small separation distances between appropriately equipped aircraft as long as the intent of the see and avoid clause is maintained.
- DDCs are designed to minimize crossing busy human-piloted VFR traffic corridors, however VFR traffic is not prohibited from entering a DDC.

Discussion Items for Future Exploration:

- Future research should explore the airspace management conditions under which DDCs are warranted, as opposed to flying on company routes or using established VFR corridors.
- Future research should explore the impacts of dynamic flexibility on air traffic manager workload and the scope of tools needed to support dynamic temporal flexibility.
- Future analysis should explore how DDC placement impacts ATC monitoring tasks to ensure IFR aircraft do not enter a DDC.
- Future research should explore how DDCs are defined in Class D airspace regions that don’t have radar service, but rather manage separation by controlling flight rates.
- Future research should explore what information (e.g., position and traffic count) should be available to local air traffic managers, and how this information should be made available.
- Future research should explore what navigation performance requirements (i.e., accuracy of containment) will be necessary for aircraft transiting a DDC.
- Contingency procedures will be needed for when an automated aircraft loses link while flying in the DDC.
- Future research should explore the extent of coordination needed with air traffic managers when defining a DDC in Class E airspace.
- Future research should explore the scope of local procedures that can be created to help dictate traffic rates within a DDC. Some procedures may be prevalent enough that they could be

established as a new set of flight rules regulated under Part 91. Possibly called Corridor Flight Rules – these would only be applicable within a DDC for use by certified autonomous systems and would be used instead of VFR or IFR.

- Future research should explore the viable traffic management solutions given a range of expected traffic densities within a corridor. Solutions may involve a centralized automated traffic control system, or a simple entry metering solution with free flight once in the corridor.
- Future research should explore the design of DDCs to minimize interactions with existing VFR traffic flows and any situational awareness tools made available for conventional VFR traffic to be aware of the location of DDCs.

Decision Support Services for Automation

UAM aircraft will need access to a wide variety of collaborative decision support information to enable safe and efficient flows of traffic. Decision support services are provided through an open architecture information exchange and may communicate both safety critical and safety enhancing information. Examples include traffic location, DDC status, meteorological information, obstruction locations, traffic coordination, and landing site information. The architecture for service provision may be similar to and possibly share elements of the UAS Traffic Management System (UTM) architecture. The main difference from UTM is that UAM services will be applicable for automated aircraft operations with longer flight distances, higher altitudes, and more stringent safety assurance applications than existing UTM services that focus on non-passenger carrying, beyond visual line of sight operations below 400 feet. Depending on their location and operation type, automated aircraft may be required to provide identification, intent, and telemetry information over the information exchange link.

Discussion Items for Future Exploration:

- Decision support information for UAM operations will need to leverage and exchange information with existing UTM services and conventional ATC services. The scope and method of information exchange between the three environments needs to be explored.
- The scope and criticality of data services will need to be explored. In addition, service provision responsibilities should be explored to identify which services are provided by FAA and which services are provided by qualified industry providers.
- A variety of communications links and exchange protocols will be possible. Additional research is needed to scope the information exchange architecture and define the criticality and performance of each provided service.
- Many UAM operations will occur in airspace regions where a Mode C transponder is required today and Automatic Dependent Surveillance – Broadcast (ADS-B) will be required (starting in 2020). Future research should identify which communication links can support identification and tracking requirements and explore the performance impacts on those links at various traffic levels.

Performance-Based Operations

The performance-based operations concept is intended to enable growth and scalability of UAM operations as aircraft are equipped with better performing technologies. UAM operators equipped with the best technologies will, in some cases, be able to fly the most efficient company-preferred route. Examples of equipage differentiating technologies include navigation precision technology, DAA technology, noise reduction technology, and vehicle to vehicle (V2V) communications technology. To best enable performance-based operations, careful consideration should be placed on understanding the impact of mixed-equipage operations and whole-system efficiency impacts. While better performing aircraft will see benefits, lesser performing operators should still be able to meet their operational business case.

Performance-based operations may open some areas of flight and some DDCs to UAM aircraft with a certain level of equipage. Some DDCs may be open to aircraft equipped with a specified level of navigation precision, providing more direct routing options to these aircraft. For example, greater navigation precision may be needed to enable flight operations through a narrow corridor. Some DDCs may be open to aircraft equipped with a specified time of arrival precision, enabling high throughput operations through a corridor. Aircraft with significantly different speed capabilities may determine throughput performance through a DDC.

Better performing DAA and V2V technologies may enable lower separation requirements within a given area of flight. For example, an aircraft with a high performing V2V equipage may be able to fly within 100 feet of another aircraft with the same equipage but may have to stay at least 1,000 feet away from a different aircraft with lower performing equipage. In the future, aircraft performance could enable dynamic separation standards.

Additionally, some DDCs may be open to aircraft meeting certain noise emission thresholds.

Discussion Items for Future Exploration:

- Future work should identify the key performance factors that differentiate better performing UAM operations, the technology life cycles driving the differences, and the forces supporting convergence of technologies.
- Future research should identify the scope of procedure design opportunities given the key performance factors.
- Future research should identify which performance capability information needs to be shared with other stakeholders. For example, conventional air traffic management systems may benefit from access to the performance capabilities of UAM aircraft to support decision making (e.g. to support on/off display indications depending on performance)
- Future work should develop a concept of operations for performance-based separation concepts.

Airspace Integration Example Concept Description

Figure 1 shows an example flight path of an automated UAM aircraft operating through a variety of airspace classes and dynamic delegated corridors. A detailed concept description is provided for each indicated segment of flight. Segments are given a descriptive indication C# to represent flight through corridors and R# to represent flight along company-preferred routes outside of corridors.

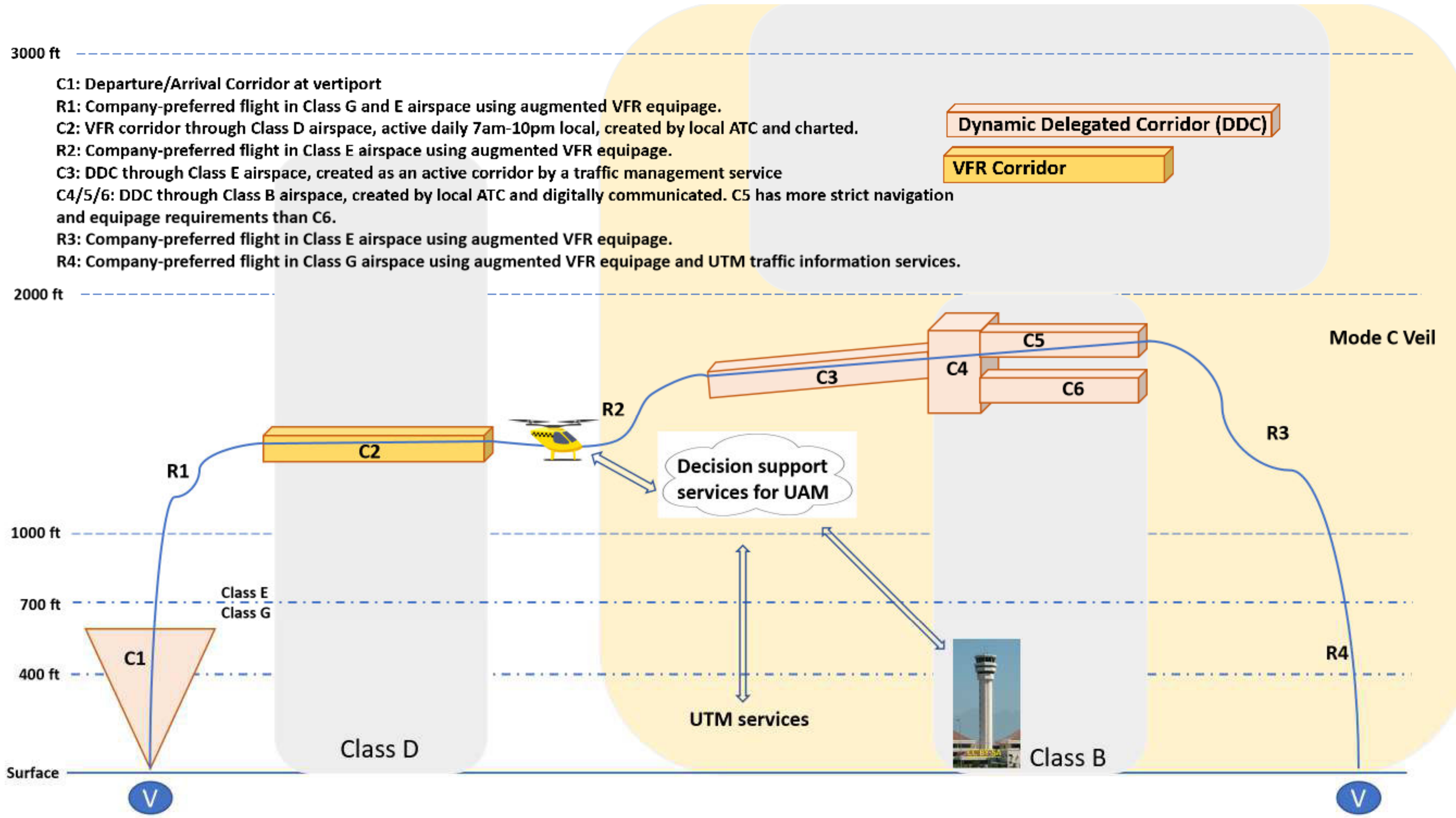

Figure 1: Notional Depiction of Airspace Integration Concepts

- C1) Aircraft depart and arrive from a vertiport in Class G airspace. When the vertiport is busy and has operations from many different UAS and UAM operators, a decision support system provides traffic management services in and out of the vertiport. During busier times, the system may define a DDC for departures and arrivals to help establish procedural separation between unmanned aircraft in the region. Aircraft planning to fly within the DDC must file intent and coordinate a trajectory with the decision support system and follow the applicable procedures established for that corridor.
- R1) The UAM aircraft gains altitude, exits the departure DDC, and enters Class G airspace. As the aircraft keeps climbing and passes 700 feet, it enters Class E airspace and reaches its cruise altitude of 1,500 feet. The aircraft is equipped with augmented VFR technology and flies a company-preferred route towards an established VFR corridor. It uses DAA equipment to avoid other aircraft as if it were like a piloted aircraft following visual flight rules. Under the Mode C veil, the UAM aircraft is broadcasting ADS-B. The broadcast includes an indication that the aircraft does not have a human pilot onboard and is using augmented VFR technology.
- C2) The UAM aircraft has an option to either fly around Class D airspace, or if equipped, fly through a VFR corridor that has been developed by the local air traffic manager. Flight within this corridor does not require ATC communication, however a specified set of procedures must be followed. The UAM aircraft must be equipped with the knowledge of the procedures of this specific VFR corridor in order to enter.
- R2) The UAM aircraft exits the VFR corridor and re-enters Class E airspace. As before, it uses augmented VFR technology and flies a company-preferred route continuing towards its destination. It then approaches a busy section of Class E airspace under the 'Mode C Veil'[7].
- C3) In a portion of the Class E airspace that is known to be particularly busy (e.g., within the Mode C Veil), an automated decision support system has dynamically established and published a DDC. Aircraft follow specific procedures and speeds along this corridor to help coordinate and smooth the flow of traffic. The UAM aircraft is not required to fly along this corridor, but determines it will get some operational benefit, since it will be less likely to have to vector around other traffic when flying within the corridor. The decision support system notifies ATC that the corridor has been established, and ATC may aid IFR aircraft in avoiding that corridor. As the UAM aircraft nears the exit point of the DDC, it approaches Class B airspace and must make a routing decision.
- C4/5/6) The UAM aircraft can either fly around Class B airspace or enter Class B airspace through a DDC. Specific equipage requirements are in place in order to enter this DDC, including a minimum navigation precision requirement and knowledge and competency to abide by all procedures associated with this DDC. The aircraft enters the DDC without notifying ATC and continues flying towards the destination. The DDC then splits into two different corridors. Corridor C5 has more strict navigation performance requirements and enables a shorter flight path than Corridor C6. Since the UAM aircraft is equipped with the needed equipment to fly in C5, it chooses that corridor and continues towards its destination. The aircraft then reaches the end of the corridor and exits Class B airspace back into Class E airspace.
- R3) As before, the UAM aircraft uses augmented VFR technology and flies a company-preferred route continuing towards its destination.
- R4) The UAM aircraft descends towards the vertiport and transitions from Class E to Class G airspace. No DDCs are in place at this vertiport, and the UAM aircraft uses augmented VFR

[7] The 'Mode C Veil' is the informal name for the airspace within 30 NM of a Class B airport in the U.S. within which use of a transponder or ADS-B is required.

technology and UTM traffic information services to avoid other UAM aircraft and other small UAS in the area.

Concept Exploration and Evaluation

Many of the questions and research topics raised above can be explored in an experimental environment where concepts and possibilities can be envisioned, analysis conducted, and consensus reached among the diverse aviation stakeholder community.

Lab Evaluation Opportunities

The primary objectives of a lab activity are visualizing and exploring the concept of allowing augmented VFR flights to fly through a variety of the following airspace situations.

- Existing VFR corridors
- Existing VFR flyways
- Class E airspace
- Dynamic Delegated Corridors in Classes B, C, D airspace
- Class G airspace below 400 feet with frequent small UAS operations

Research questions include:

- What are the impacts to air traffic managers controlling that airspace?
- What are the impacts to other VFR traffic in that airspace and other IFR traffic in the vicinity?
- What decision support capabilities may be needed for ATC? For UTM? For other operators?
- What procedural changes/additions are needed to enable the operation?

Visualizing these concepts and performing thought exercises with a variety of stakeholders will help refine concept details, identify needed decision support information, identify needed information flows, and explore potential roles and responsibilities for future operations.

These concepts can be explored across a range of different traffic situations reflecting anticipated technology maturation and traffic densities. This will help provide an understanding of possible implementation timelines and system needs over time. Visuals can help identify the range of viable routes (of various types) between select origin/destination pairs in a metro region, given the concepts presented in this paper.

These concepts can also be explored in the context of important off-nominal situations. For example, visualizing an aircraft deviating from a DDC possibly into controlled airspace can help understand the sequence of events to mitigate safety hazards and rectify the situation.

One such environment is the MITRE Integrated Demonstration and Experimentation for Aeronautics (IDEA) Laboratory.

MITRE IDEA Lab

For the past 20 years, MITRE has been using the IDEA Lab primarily located in McLean, Virginia as a robust environment capable of evaluating a range of exploratory concepts, while also being realistic enough to enable high fidelity simulations. The IDEA Lab's integrated capabilities, such as numerous cockpit simulators, a Tower simulation, Air Traffic Control decision support displays, and instances of the

FAA's traffic management capabilities (e.g. Time Based Flow Management, TBFM) enable human-in-the-loop (HITL) simulations, demonstrations, and visualizations.

Working in the IDEA Lab together with the Federal Aviation Administration, National Air Traffic Controllers Association, Air Line Pilots Association, civil aviation authorities of various countries, and other organizations, MITRE has helped improve aerospace systems in a number of key areas, such as airspace redesign, controller training prototypes, airport/runway siting, and incorporating UAS into the NAS.

Figure 2: Picture of the Tower environment in the IDEA Lab.

The existing infrastructure and flexible design of the IDEA Lab provides an excellent environment to evaluate and iterate on the airspace integration concepts discussed in this paper. The IDEA Lab provides an environment for all parties to share the experience of a proposed concept, discuss their perspectives on workload, communication, safety, efficiency, roles and responsibilities, as well as other topics. Visualization, iterative changes, and evaluations allow the parties to come to an agreement quickly and lead to faster implementation of beneficial enhancements.

Summary

In this paper we lay out four concept components that could enable the routine integration of UAM traffic in existing terminal area airspace with minimal operational changes to existing rules, policies, and procedures and with minimal disruption to existing flight operations. However, additional research is required to further develop, explore the implications, and evaluate the feasibility of such concepts. Leveraging simulation capabilities such as MITRE's IDEA lab is one such means to explore and evaluate.

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