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AN INTERNATIONAL RESEARCH PERSPECTIVE ON AIRSPACE INTEGRATION IN THE FRAMEWORK OF URBAN AIR MOBILITY

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Abstract

Urban air mobility (UAM), also known as advanced air mobility operations (AAM), offer both opportunities and challenges for air transportation systems. This paper presents initial results from a scientific assessment conducted by IFAR experts on the airspace integration. The technology area overviews and state of the art assessment identify differences and commonalities across countries as AAM concept are explored and developed. In addition to conceptual development across IFAR member nations, a gap analysis was also preformed that incorporates both early and long-term use cases and outlines key areas of research required to safely integrate UAM operations into air traffic management systems around the world. Leveraging existing technologies can enable early integration. The needs for international standardization across terms, operational concepts, methods of integration with existing airspace users, traffic management concepts and needed capabilities, and guiding rules are also discussed.

Keywords: advanced air mobility, urban air mobility, airspace integration, standardization, technology gap analysis

1. Introduction

Across the world, new innovative aircraft vehicles, ranging from small unmanned aerial systems (sUAS) or drones to larger passenger carrying electric vertical takeoff and landing (eVTOL) concepts, are being developed that have the ability to transform the role of aviation in everyday life. These vehicles have unique operational characteristics that are not currently provided for in current Air Traffic Management (ATM) systems around the world. In addition to new operational characteristics, these operations are expected to increase traffic density and tempo, when compared to existing traffic loads. These operations are also characterized by increasing levels of automation in the flight deck and for ground systems as well as needs relative to infrastructure as vehicles plan to operate across metropolitan centers as well as across regional and rural environments. Combined these factors present unique operational challenges and research needs particularly in the field of airspace integration.

As the UAM industry and research community has grown and developed, there have been several concepts and visions written and published that outline potential operational concepts, roadmaps and use cases. These include concepts and visions from the FAA and NASA in the United States [1], [2], concepts from EASA [3] and EUROCONTROL [4] in Europe, as well as from METI and MLIT in Japan [5].

Given the development and research ongoing across many countries in the world, the International Forum for Aviation Research (IFAR) established a group of experts from member nations to collaborate and share information on burgeoning UAM capabilities and concepts. The group of experts cover several topics ranging from vehicle development and automation to vertiport operations. This paper is focused on the collaboration of the IFAR experts from the Airspace Integration and the initial work identifying common research areas that may require international harmonization.

1.1 A Note on Terminology

It should be noted that throughout this paper the term Urban Air Mobility (UAM) is used, which refers to the use of innovative aircraft configurations (e.g., eVTOLs) enabling efficient, and safe operations within and over densely populated urban areas. However, the use cases detailed below and relevant technologies extend beyond urban environments. In the United States, the Federal Aviation Administration (FAA) and NASA have defined a broader term, Advanced Air Mobility (AAM) [6], which includes a broad set of vehicles, innovative technologies, and covers urban, regional, and interregional operations. There are, however, no officially agreed upon definitions and scope of operations covered by both terms, as highlighted in a report by the European Union Aviation Safety Agency (EASA) [7]. Nevertheless, for the purpose of this paper, it was assumed that UAM and AAM are considered as coherent concepts. Furthermore, the line between unmanned aircraft system (UAS) traffic management (UTM) operations and UAM operations predicted to use U-SPACE [4] also blurry and needs further discussion in the research community[1].

2. Overview of Operations and Use Cases

As stated above, new entrants such as sUAS and passenger or cargo carrying eVTOLs will need to be safely integrated amongst traditional and existing transport mechanisms. From an airspace perspective, a flight today is currently managed and separated safely from other users, regardless of it being passenger or cargo, manned or unmanned. To investigate how new entrants can be integrated in safe and efficient manner, the team considered UAM use cases discussed around the world and examined existing technologies and gaps which need to be addressed to realize such use cases. The findings presented in this section do not necessarily cover all potential scenarios and are intended to provide an initial international perspective on the relevant research questions.

Generally, UAM operations, as described by the various concepts of operations across the world, are consistent in highlighting four key areas. These areas include 1) development of vehicle technologies and automation, 2) development of ground infrastructure and services such as a vertiport, 3) development of novel airspace design and procedures, and 4) development of traffic management systems to support a variety of use cases. The focus of this paper is on the airspace integration challenges referenced in airspace design and traffic management system integration. These operations are also characterized by a combination of three primary attributes: traffic density, operational complexity, and reliance on automation.

The integration of UAM operations generally suggest new airspace structures as well as evolving roles and responsibilities for existing system entities such as air traffic controllers and operators. The referenced concepts imply UAM airspace integration should be safe and efficient with minimal impact on existing air traffic management systems. Some concepts propose increased level of automation for air traffic controllers and a shift to distributed architecture versus the more traditionally established centralized architecture. In addition to airspace integration, the operational concepts also recognized the need for integration between airspace and vertiport operations. As capabilities and automation is planned for ground services and landing surface for UAM, there is expected to be information exchange between airspace services and vertiport operations to ensure that landing locations are available along with a host of other data such as weather and surveillance at the landing site. To scale operations, a digital exchange of information between airspace services and vertiport operators is expected. This integration will be required for scalable, high density and volume operations. Regionally focused ConOps are possible, but a certain level of compatibility is necessary from an operator's perspective to develop towards a standard set of requirements, procedures, and rules. However, local rule possibility/adaptation should remain, perhaps following certain minimum requirements defined by the global community.

This construct allowed for the development of two categories of use cases to consider for airspace integration challenges and areas of research: early or near-term use cases and long-term use cases.

[1] U-SPACE, similarly to UAM corresponds mainly to the urban areas being open on needs of the cities with regard to various aspect of integration of UAM operations within urban transport systems

In this construct, the international team agreed that early use cases would be characterized by the inclusion of sUAS integration and piloted operations for transport whereas the longer-term use cases would enable increasing levels of automation on board the vehicle and ground systems that reduce the dependency of humans in the overall system.

There are various interpretations relative to the timeframe of early use cases and their operational integration, but in this paper, we consider early use cases for UAM operations to be realized between 2025 and 2035. Long-term use cases are anticipated to be seen after 2035. This approach is complementary to both the United States' UAM Maturity Level (UML) timeframe [8] and with the approach assumed in SESAR H2020 X-TEAM D2D UAM project [9]. The SESAR project for example outlined three horizons: reference perspectives in 2025, near-term perspectives in 2035, and long-term perspectives aimed at 2050. The air mobility roadmap developed by METI in Japan considers several development and implementation stages: early 2020s, mid 2020s and 2030 and onward [10].

2.1 Early (near-term) Use Cases

Early (near-term) use cases vary across the world. Nevertheless, some applications seem to be commonly expected as more probable and capable of integrating into airspace constructs both from an operational perspective as well as regulatory. Following among other results of Europe's ASSURED-UAM project [11], NASA's AAM research [2], and JAXA's research [12], [13] two major early use-case groups: point-to-point transfer of goods and passengers and public good (also known as emergency) services.

2.1.1 Point-to-point Transfer of Goods and Passengers

Near term operations are anticipated to enable the transfer of goods and passengers on established routes using potentially new infrastructure and evolving operational constructs. The most frequently referenced use case is the air taxi, which will operate in similar manner as in time of writing of this paper on-demand air-taxi, i.e., their take-off and landing locations will be vertiports (may include existing airports on be located within urban areas) [6], [10]. In this near-term scenario, low volume operations carrying passengers will occur leveraging vehicles with piloted configurations and utilizing existing airspace constructs, procedures, and rules. Early uses cases predominantly consider early passenger carrying UAM flights to be piloted [8], [11] . However, the implementation and operational considerations depends on the world region, regulatory changes along with the attitudes of governing bodies, as well as the risk associated with the type of operation (such as flights overpopulated regions).

While it is anticipated that passenger carrying operations will occur piloted, in the case of transport of goods the majority are envisioned to be remotely piloted or automated operations with no pilot on board [11]. Last-mile delivery is frequently discussed as one of early cargo-UAM use cases. These operations offer the benefit of providing access to difficult to access or remote regions, for example, the transport of goods to remote islands and suburban areas in Japan [5]. These operations may not be dependent on new infrastructure, such as vertiports, and therefore can function where the ground infrastructure does not allow for timely and/or efficient delivery services. UAM operations can extend the connectivity of such regions by enabling the transport of goods.

2.1.2 Public Good Operations

Public good operations have been in the spotlight since the beginning of UAM use case discussions in many countries. The term public good is used to cover services such as the transport of people or goods for medical purposes, supporting disaster relief operations, enabling new modes of combating wildfires, as well the transport of people due to an emergency (such as an air ambulance).

Early sUAS and manned aircraft integrations have been tested and discussed in Japan and the United States, for example, and therefore an extension to UAM operations comes as the next step [12], [14]. Two major types of public services (emergency) operations can be identified: new entrants substituting traditional vehicles in existing operations and new missions/operations made possible thanks to the extended capabilities offered by new entrants. Transport of injured people, necessary medical equipment and supplies have been shown to receive high public acceptance as well. Some initial steps in such expanding operations include transport of blood samples [15] and defibrillators [16] by sUAS have been demonstrated in Europe already.

2.2 Long-term use cases

As opposed to scheduled, point-to-point operations in the near-term use cases, long-term operations are envisioned to include on demand operations, increasing complexity of operations, higher levels of automation, and higher volumes of traffic [2], [11]. Air taxis and personal eVTOL operations, including free routing are part of such long-term visions published worldwide [3] , [5] , [6]. In addition to expansion to on demand use cases, the long-term use cases are often characterized by an increasing scale or volume of AAM or UAM operations. To accommodate this, UAM flights may use novel airspace structures such as corridors and/or operation volumes to provide strategic separation from conventional aircraft and to assign routes when required. As traffic levels increase, the structure of the novel airspace such as corridors may become more complex. Increased level of automation (e.g. remotely piloted eVTOLs, remote ids, and such) will be introduced as the system is tested and validated and after adequate trust has been built with human agents in the system.

Alongside advances in automation, long term use cases will require a transition to secure and consistent digital infrastructure networks that will enable vehicle to ground communications as well as vehicle to vehicle communication considerations. Long-term use cases will also see an increase in variety and complexity of public and emergency services operations, including more integrated operations with existing aircraft. In addition to an increase in complexity and mix of operations, there is the expectation that there will be more routine operations over more densely populated areas. This use case is not only dependent on advances in technologies referenced above but is also predicated on evolving policies and regulations worldwide.

3. Integration with Existing Aviation Users and Systems

Integration with traditional traffic, sUAS and other new entrants is necessary for safe and efficient UAM operations. UAM vehicles are expected to operate in airspace ranging from 2000 ft to 10,000 ft AGL depending on vehicle configuration and performance characteristics. Integration with conventional air traffic will be needed where demand exists. During nominal operations, integration with traditional ATM stakeholders will be essential. In the United States, for example, focus is placed on 3000 ft AGL and below (Class G) airspace and airport vicinities. In many airspaces worldwide, UAM integration in managed airspace will require solutions to limit interaction with ANSPs and air traffic controllers to prevent burdening existing air traffic management systems. It is anticipated that there will be challenges in integrating UAM operations in uncontrolled airspace where there may be more aircraft flying under visual flight rules (VFR).

Current sUAS operations occur in very low airspace, while ceilings might differ slightly in different countries, these operations generally occur either below 400 or 500 ft. There are expected interactions between UAS Traffic Management (UTM) systems and UAM operations. Terminal operations are of specific interest given that in most countries UAM operations are envisioned to use the altitudes above UTM airspace, except for transitions to land or depart. In many worldwide locations UTM is deployed to aid safe and efficient sUAS operations at very low altitudes [17], [18] [19], [20]. Some concepts envision sUAS traffic management systems to be leveraged and developed further to manage UAM flights as well. However, there is no consensus worldwide on this research area. Some countries envision a single system [21] for both sUAS and UAM operations while others expect similar federated concepts to apply to UAM but with potential architectural and conceptual differences given the complexities of passenger carrying operations. While UTM focused on parts of the airspace which were rarely used by traditional aviation, UAM vehicles will fly in airspaces which are already occupied by existing users, so the necessary level of integration is significantly higher. In addition to conventional and sUAS integration, public good missions will also require more interaction with low-altitude operations, as missions such as search and rescue and airlift include low-altitude segments.

The need for integration with existing aviation calls for a multi-layered approach. Integration of information from traditional traffic and new entrants needs investigation. Increased levels of automation are also needed, especially for long-term operations which will be characterized by higher densities and more complexity.

4. Key Areas of Research for UAM Airspace Integration

In addition to an assessment of use cases and common operational characteristics, the IFAR experts team conducted a gap analysis and determined there were several key areas of research that may require global harmonization. The key areas of research include

- Intent Sharing
- Separation Minima
- Collaborative Conflict Management
- Communication, Navigation, and Surveillance

- Airspace Design and Procedures
- Airspace and Vertiport Interactions

As discussed earlier in the paper, airspace and vertiport design and interactions are considered in each ConOps. While geographic location also plays a role there are many commonalities that are required for UAM operators and avionics developers to support seamless flights at various global locations. In Europe, for instance, more standardization might be needed as too many local ConOps will obscure operations. Therefore, it is safe to assume that some elements need harmonization, in particular at a high-level) while still allowing for regional adaptations and these are to be further defined by the international community.

Below are some more detailed discussions on the remaining four areas of research.

4.1 Intent Sharing

Intent sharing is paramount for deconfliction at all levels and regardless of use case. At a strategic level, novel airspace structures under research and development such as U-Space, UTM operational volumes, and UAM corridors all rely on a certain level of intent predictability and sharing. At a tactical level, self-separation technologies are required. Intent sharing includes informing all users of the airspace about users and use cases across UTM flights, UAM flights and traditional aviation. Enabling intent sharing and shared situational awareness to inform flight planning may require new performance and operation requirements for operations sharing airspace with UAM flights.

As technology develops such as advanced Detect and Avoid algorithms, noise reduction capabilities, precision navigation technology, and vehicle-to-vehicle (V2V) communications and use cases evolve so will information requirements. It is assumed that more capable aircraft will be able to fly the most efficient preferred routes, however, the impacts of mixed-equipage flights on the system must be carefully investigated and understood.

Therefore, trajectory prediction and intent sharing would be needed for current users which are currently not used to or required to provide such detailed flight plans or certified mechanisms that will enable conflict detection and avoidance of non-cooperative traffic. Therefore, robust situational awareness, reliable flight planning and de-confliction technologies are going to be necessary.

4.2 Separation Minima

Separation minima need to be defined for UAM-UAM, UAM-UTM, UTM-ground vehicles, and UAM-Traditional traffic. Separation minima are established based on vehicle performance and operation characteristics, but data on UAM vehicles are not readily available. However, research towards UTM separation minima and ground vehicles is an area of exploration in Europe [22]. Furthermore, given that operational rules to be adopted for UAM are still under discussion, separation minima are not necessarily analogous to existing definitions in manned aviation. In addition to fixed separation minima, dynamic separation should be considered to support adaptable airspace integration needs and a variety of use cases such as those under the public good umbrella.

Diverse configurations, a range of performance characteristics, and various operational environments call for new approaches to determining separation minima. Airspace configuration, integration with UTM and ATM, vehicles' capabilities and risk assessment should all play a role. Once separation minima are defined, traffic density can be quantified, and this will allow researchers and practitioners to analyze differences and commonalities among various airspaces and UAM operations.

4.3 Collaborative Conflict Management

As concepts for intent sharing develop over time and across use cases, consideration must be made for conflict management in a cooperative sense across both strategic and tactical realms. ICAO's Global Air Traffic Management Concept [23] defines conflict management across three layers: strategic, separation provisions, and collision avoidance. As UTM developed and the need for a federated system that would allow for conflict management in a collaborative sense grew and leveraged the traditional three layers with the additional component of shared responsibilities across operators [24]. This concept should be extended and applied to UAM airspace integration but with the appropriate risk-based approach for passenger carrying operations and severity of occurrence.

Key enablers of collaborative conflict management include services for demand capacity balancing, airspace structures, separation and flow management, and Detect and Avoid capabilities. Currently right of way rules for VFR leverage See and Avoid (FAA Part 91.113) as the primary mechanism to prevent a loss of separation and ensure collision avoidance. The IFAR experts agree that this concept needs to evolve to sense and avoid allowing for regular sUAS operations and remotely piloted UAM operations. The concept of sense and avoid is a combination of hardware, sensor fusion capabilities, and algorithms to remain clear of potential conflicts that allows vehicles to avoid hazards and collisions. This has been identified as a key enabler for UAM operations.

For tactical separation, UAM pilots in near term use cases will leverage see and avoid to visually detect and maneuver around other aircraft, but this not a safely scalable option. Other separation methods are being developed, such as automated, on board "detect and avoid" systems. DAA will be needed as traffic levels increase. Good human factors design of software used by pilots and operators will contribute towards the safety of UAM operations. In addition, collision avoidance can be accomplished by using strategic collision avoidance algorithms, avoidance maps, and path planning [21].

UAM and AAM operations not only interact with manned aviation, but there are several points of contact with ground based manned and autonomous vehicles and potentially objects such as cranes especially in the U-Space. Current research in Europe is focused on deconfliction of sUAS and ground vehicles. This work includes development of a tactical conflict management system that can be used to simultaneously handle UAM and ground traffic in a safe and efficient manner [22].

While collaborative conflict management may be feasible for cooperative traffic, equipage and performance requirements need to be considered in planning for airspace integration across a variety of use cases. This is particularly true for use cases in which surrounding vehicles may not be sharing intent information actively.

4.4 Communication, Navigation, and Surveillance

Resilient and secure communication, navigation, and surveillance (CNS) infrastructure was also identified as a key enabler for UAM operations and airspace integration. These capabilities will enable digital information exchange between a vehicle and ground operators, operators and ANSPs, vehicle to vehicle, and other services that may be needed to perform operations in an increasingly automated fashion. In addition to communication links, accuracy and reliability of navigation and surveillance capabilities is needed to support UAM operations at lower altitudes as is expected for sUAS and UAM operations. Navigation capabilities will also allow for increasing performance-based navigation, trajectory-based operations, operations in various weather conditions, and will be required for longer-term UAM use cases as operations scale [2], [25]. CNS infrastructure will support collaborative conflict management, precision approach and departure procedures, and the ability to account for non-cooperative traffic.

In addition to the technological development needed the IFAR team identified that various regional challenges should also be considered. Remote and rural areas may not provide sufficient availability and accuracy of navigation and surveillance capabilities. In urban areas, building structures and extensive traffic may prevent traditional radar capabilities from functioning as intended. This area requires significant research and collaboration to develop potential solutions and identify which aspects of the CNS framework require harmonization.

5. Evolution of Roles and Responsibilities for Actors

Another area of research identified by the IFAR experts is the need to detail the new actors or entities that may be required to conduct UAM operations in both the near term as well as long term; in addition, to new actors it was determined that a functional allocation of the roles and responsibilities of all the actors, both new and existing, in the two use cases is also needed.

The IFAR experts agreed that the near term use case for operational integration of UAM aircraft will depend on existing entities in the system to facilitate operations. These entities include a pilot in command (PIC) on board on the aircraft, the operator, as well as air navigation service providers. However, as use cases scale and evolve over time there will be additional entities that must be considered in terms of both digital interactions as well as functional allocation. The US [1], Europe [4], and Japan [10] have identified that as demand increases additional actors may be needed for fleet operators, remote pilots in command, vertiport operators, third party airspace providers and their networks, as well as roles for local municipalities and government organizations.

6. Implications on Policy and Regulations

As noted in the collaborative conflict management section, existing flight rules and procedures may be sufficient for near term use cases, however, to enable the scalability of operations and increasing levels of automation there will be a need to address elements via policy and regulation changes. The policy and regulation considerations would range from airspace structures, procedures, flight rules, and other considerations needed to enable farther term use cases. Several regulations have already been published in Europe, such as the U-Space airspace regulations (EC Regulation 2021/664), together with two regulations for manned traffic operating in U-Space and vice versa (2021/665 and 2021/666) [26]. In addition, regulatory authorities across the globe are developing means of compliance for eVTOL vehicles while also gathering data through simulation and flight test to understand how policy could evolve to support scalable and safe UAM operations.

7. Concluding Remarks

Urban air mobility (UAM) vehicles will need to be safely and efficiently integrated into existing airspace with traditional aviation, small unmanned aircraft systems (sUAS), and other potential new entrants. The implications of integrating UAM vehicles touch upon many areas under airspace, including airspace design and procedures, evolving functional allocation between traditional air traffic service providers (ANSP) and new entities, technologies to enable digital information sharing, surveillance and navigation capabilities, as well as policy, flight rules, and regulations. Concepts of Operations (ConOps) have been under development around the world from both industry as well as ANSP organizations; these ConOps require harmonization for international operations while also allowing for regional adaptation. Ongoing international research aims at filling the technological gaps and realizing UAM.

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9. Copyright Statement

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