Development of Candidate Airspace Procedures for Urban Air Mobility in the Dallas Area

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***Abstract*— As the concept of on-demand electric air taxis gains popularity and begins to take shape, many research efforts are underway to address the challenges of integrating this new class of passenger-carrying air vehicles into the already congested U.S. National Airspace System. Through collaborations between the National Aeronautics and Space Administration (NASA), the Federal Aviation Administration, and industry, this concept, commonly referred to as Urban Air Mobility (UAM), envisions a safe, reliable, and efficient mode of transportation traversing metropolitan and urban areas. Among the many challenges being tackled, airspace procedures and information requirements are critical areas of research that need to be addressed. In a joint effort between NASA and Joby Aviation, a human-in-the-loop study was conducted at the NASA Ames Research Center to evaluate initial and midterm operations with air traffic controllers and on-board UAM pilots in the Dallas area. This area was chosen due to its complex Class Bravo Airspace that extends to the surface over a relatively large area. To achieve the goals and objectives of the study, multiple preceding efforts were conducted to develop the candidate procedures and information requirements. This paper provides an overview of the operational concept used for the study, the process that was followed, and the findings from the two tabletop meetings and a shakedown activity. The combination of these led to a set of airspace procedures, letters of agreement, and information requirements that were evaluated in the human-in-the-loop study.**

Keywords—advanced air mobility, AAM, air traffic control, ATC, air traffic management, ATM, airspace procedures, class bravo airspace, concept of operations, ConOps, controlled airspace, corridors, electric vertical takeoff and landing aircraft, eVTOL, FAA, Joby Aviation, NASA, routes, information requirements, initial UAM operations, letter of agreement, LOA, midterm UAM operations, part 135 operations, pilot-in-command, PIC, urban air mobility, UAM, UAM operations

I. Introduction

The world of aviation is constantly advancing with innovative concepts and technologies, and with that comes a great responsibility to maintain the safety and efficiency of the U.S. National Airspace System (NAS). Among these advancements lies a fast growing, soon to become reality, concept known as Urban Air Mobility (UAM); a highly anticipated and revolutionary form of on-demand air travel, which "leverages the sky to better link people to cities and regions, giving them more possibilities to connect" [1]. This idea to better connect people within urban locations hinges on the notion of using small electric vertical takeoff and landing (eVTOL) aircraft that are designed with cutting-edge technology and automation, and are anticipated to carry approximately four to six passengers. It is expected that these aircraft will operate in both controlled and uncontrolled airspace, and in a manner similar to current-day helicopters operating under Part 135 certification per the Federal Aviation Administration's (FAA) Title 14 Code of Federal Regulations (14 CFR Part 135) [2] [3]. The FAA grants Part 135 certificate holders "the authority to operate on-demand, unscheduled air service" [4].

Version 2.0 of the FAA's Concept of Operations (ConOps) for UAM operations [2] provides an overview of the "iterative progression of work in the development of the concept" that is aimed at developing an air transportation system that moves people and cargo in "locations not previously served or underserved by aviation." It covers an expansive range of topics, including principles and assumptions for UAM operations, cooperative operating practices, roles, and responsibilities of key system actors (human and automation), and scenarios among other topics. The assumed evolution of UAM operations is also discussed in the ConOps, which details

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the assumptions for initial, midterm, and mature state operations.

According to [2], initial UAM operations are expected to start at a low operational tempo. It is also assumed that airspace operations would be consistent with current-day airspace rules and regulations, and with local letters of agreements (LOAs) in place. Existing air traffic services and routes would be used and new routes would be established only as necessary. Initial UAM operations are also expected to fly with a single, on-board, pilot-in-command (PIC) in the cockpit. Since initial UAM operations will be subject to current-day airspace rules and regulations, the UAM PIC will be expected to communicate with air traffic control (ATC) to conduct operations in and out of Class Bravo, Class Charlie, and Class Delta controlled airspace in the vicinity of airports [5].

The operational temp for midterm UAM operations is expected to remain low. It is assumed, however, that it will have enough increase that would require changes in existing regulatory framework and airspace procedures. A performance-based cooperative environment, such as a UAM corridor system, would be introduced with new or modified airspace procedures and updated regulations. It is expected that the constraints on ATC workload will be a limiting factor on the tempo and density of emergent UAM operations [5]. As such, strategies to reduce ATC workload need to be established given the anticipated increase in operational tempo during midterm operations, such as a reduction in communications and tactical ATC control during nominal situations. Mature state operations expects a significant increase to the operational tempo, have higher levels of aircraft automation, and frequent remotely piloted vehicles.

With the vision of new opportunities for air travel, the UAM concept, which is part of the overall Advanced Air Mobility (AAM) [6] air transport system concept, comes with its own unique set of broad challenges that need to be addressed prior to their rendezvous with the NAS. These challenges range in issues from airspace integration and communications to several human factors considerations, such as design of displays, information flow and requirements, and roles, responsibilities, and accountability among others. Much research is also needed in order to assess the appropriate levels of operational tempo for each evolutionary stage of UAM operations in order to maintain safety of the NAS.

In an effort to tackle a subset of the aforementioned challenges, a joint effort between the National Aeronautics and Space Administration (NASA) and Joby Aviation was conducted at the NASA Ames Research Center in Mountain View, California. This effort, which was conducted in 2023, aimed to investigate and evaluate candidate airspace procedures in the Dallas, Texas airspace for UAM operations. It consisted of a human-in-the-loop (HITL) simulation as a follow-up to a previous NASA study [7]. In [7], existing helicopter routes in the Dallas area were compared to a modified set of prospective initial UAM airspace procedures through a defined hypothetical LOA. These existing helicopter routes were used for comparison purposes only; candidate UAM airspace procedures and routes would not replace helicopter routes.

This paper explains the method in which candidate airspace procedures for UAM operations in the Dallas area were reviewed, refined, and developed in preparation for the joint NASA-Joby research effort, known as the air traffic management interoperability simulation (AIS) HITL. AIS focused on nominal use cases during initial and midterm UAM operations.

II. Airspace Analysis and Procedures Development

Previous NASA research and analyses were conducted to analyze an appropriate airspace for potential UAM operations that subsequently led to the development of candidate airspace procedures. This section provides a review of these previous research and analyses, which were the backbone for how the candidate airspace procedures for UAM operations in the Dallas area were reviewed, refined, and developed for the AIS HITL.

According to [5], initial UAM operations are expected "to demonstrate the potential benefits of UAM to the general public and metropolitan areas." These operations are expected to gather preliminary feedback, such as noise, from surrounding communities, and gain support for initial commercial operations. In an attempt to analyze existing airspace as a starting point for emerging UAM operations, eight metropolitan areas with FAA published helicopter route charts were investigated, including the Dallas area. Helicopter routes are designed in a manner that mitigate societal concerns, such as increased noise, by overlaying highways and freeways on the ground, which also provides visual reference for pilots while in the air. Existing corridor structures were also analyzed, such as the Los Angeles Special Flight Rules Area (SFRA), which consists of two routes. Flights flying northwest within the Los Angeles SFRA operate at 4,500 ft mean sea level (MSL), while those flying southeast operate at 3,500 ft MSL. It is expected that whether UAM flights fly along helicopter routes, inside of corridors, or other airspace constructs, they are anticipated to operate in the vicinity of all other types of aircraft. These include manned and unmanned aircraft operating under instrument flight rules or visual flight rules (VFR). The UAM airspace integration effort conducted by NASA focused on enabling early entrants into the NAS and explored "possibilities for the services, procedures, and tools necessary to support high-tempo, high-density mature operations."

In theme with that effort to focus on integrating UAM into the NAS and exploring possibilities to support future mature operations, several ConOps [8] and roadmaps [9] were developed to address challenges. In [8], the FAA introduced new technology, such as the Provider of Services for UAM, and new airspace structures (e.g., corridors). NASA research used the vision provided in [8] as a guiding point to explore low tempo UAM operations using "existing helicopter routes, helipads, policies, and regulations as well as present-day ATC services" [7]. In order to create a common framework for reference, NASA generated a model for how UAM operations may evolve (Fig. 1). This model showcased three overall categories and six UAM maturity levels (UMLs). Each level corresponded to "specific stated goals and defining characteristics."

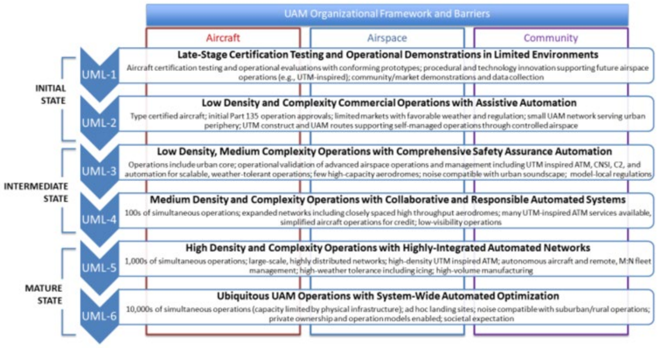

Fig. 1. The three UML categories used as a common framework of reference in [7]. The three categories were defined as initial state (UML-1 and UML-2), intermediate, or midterm, state (UML-3 and UML-4), and mature state (UML-5 and UML-6).

With these UML goals and characteristics in mind, [7] focused on near term UAM operations in the greater Dallas metropolitan area while also considering plans for future UML levels. The Dallas area encompasses three major airports that are of interest for UAM operations. These areas of interest include the Dallas/Fort Worth International Airport (DFW/KDFW), the Dallas Love Field Airport (DAL/KDAL), and Addison Airport (ADS). NASA, in collaboration with Joby Aviation (previously Joby Elevate), identified use-cases, routes, airspace procedures, and tools that were currently available in the NAS to support initial UAM operations. The objective of the investigation was to demonstrate how the airspace could be used by UAM aircraft during initial operations "with the anticipated capabilities and performance characteristics" of the eVTOL UAM aircraft.

Use cases, which were mostly considered nominal operations, included UAM routes within airspace that was largely deconflicted from traditional air traffic at varying altitudes. One use case, however, focused on the diversion of a UAM flight from a Class Bravo Airspace to a Class Delta airport. Other criteria included an FAA requirement in which ATC "must provide wake turbulence advisories to aircraft with less than 2,500 ft lateral or 1,000 ft vertical separation" [7]. Multiple assumptions were made concerning the airspace, including UAM aircraft operating under VFR and DFW and DAL airports operating in South Flow. All operator roles were assumed to be fulfilled by a human, including having a single, on-board, UAM PIC.

Other analyses conducted in [7] included an analysis of crossover traffic over a published helicopter route known as "Spine Road." The goal of this analysis was to examine low altitude crossovers that were less than 1,000 ft above the expected UAM aircraft maximum altitude, which was assumed to be 900 ft MSL. An analysis of the Spine Road route itself was also conducted. The intention of this analysis was to "determine if the UAM routes employed in the use cases were procedurally separated from conventional traffic."

The findings from [7] revealed that initial, low-tempo, UAM operations could occur in busy terminal areas (e.g., DFW, DAL) under current-day airspace procedures. However, they would face significant challenges with increased tempo and when "some desirable flight paths are constrained by existing traffic."

Similar to investigating routes for initial UAM operations, the design and analysis of corridors for midterm operations was also conducted in the Dallas metropolitan area [10]. The process to design corridors began by analyzing unused airspace surrounding the three major Dallas airports (DFW, DAL, and ADS). Researchers evaluated "standard instrument departures (SIDs) and instrument approach procedures (IAP) to identify the airspace demands of traditional traffic around DFW in South Flow only." South Flow was chosen since DFW predominantly operates in this configuration. Further evaluation was also conducted using historical track data to ensure UAM flights were outside the criteria for wake turbulence advisory. The information gathered to conduct the analysis were obtained from the NASA Ames Sherlock data warehouse. Corridors were designed to be located only in the Class Bravo and Class Delta airspace. Tracks, or predefined routes, were housed within the corridors and connected 34 potential vertiports in the region.

The results of [10] showed that all corridors designed met the wake advisory criteria in the DFW South Flow configuration; however, certain segments did not meet that criteria in the DFW North Flow configuration. It was observed that the Spine Road route did not meet the Class Bravo separation criteria in either the North or South Flow configurations. This is due to Spine Road's placement and geometry, and its proximity to the arrival flows of DFW runways 17R, 17C, 18R, and 18L.

The collective findings from these NASA research efforts paved the way for future research efforts.

III. Review and Refinement of Procedures

In an effort to review and refine candidate airspace procedures, and in preparation for conducting the joint NASA-Joby HITL stimulation, two tabletop exercises and a shakedown were conducted with subject matter experts (SMEs). This section presents details related to each preparation activity, including participants, topics discussed, and the outcome of those discussions.

Two discussion-based tabletop sessions were conducted with the objective of exploring notional, candidate airspace procedures and information exchange requirements between ATC and the UAM on-board PIC. SMEs were invited to attend these sessions in person at the NASA Ames Research Center to discuss several airspace use cases and the details of two notional LOAs. A virtual option was provided for those unable to attend in person. The set of use cases and routes/corridors presented to the SMEs was jointly developed by NASA researchers and Joby Aviation and included narrated scenarios for both initial and midterm UAM operations in the Dallas area. The Dallas area, including DFW and DAL, falls under the complex Class Bravo Airspace. This area also includes the cities of Denton, Frisco, Garland, and Arlington. Fig. 2 shows a VFR sectional map of the DFW Class Bravo Airspace.

Fig. 2. VFR sectional map of the DFW Class Bravo Airspace.

A total of six, nominal use cases were developed to evaluate the impacts of integrating UAM aircraft into the NAS in the Dallas Class Bravo Airspace. These use cases were designed based on the set that was previously developed in [7] with feedback from the FAA, and were used for assessing initial and midterm UAM operations (Fig. 3). For midterm operations, however, the airspace procedures, along with their accompanying LOA, were modified to reflect the goal of reducing communications, and thus workload, between ATC and the UAM on-board PIC. The following assumptions were made and applied to all use cases:

- Operations within the DFW airspace were to be in South Flow
- Single, on-board PIC
- VFR
- Visibility: Visual Meteorological Conditions (VMC)
- UAM aircraft treated as a helicopter (rotor-wing)

Fig. 3. Overview of routes developed for initial UAM operations. Vertiport locations are represented with a star symbol for reference. Numbers represent the six use cases, which were used for both initial and midterm scenarios.

LOAs were also created for both initial and midterm operations. These LOAs stipulated predetermined Class Bravo Airspace entry and exit procedures, landing and departure advisories, and ATC coordination points.

A. Tabletop Session 1

The first tabletop session was conducted over a span of two full days in May 2023. The NASA-Joby research team and four retired air traffic controller SMEs from the DFW metropolitan area participated in this session. These four SMEs were recruited as part of the research team. Their feedback and expertise supported the refinement of the proposed candidate airspace procedures and routes/corridors, which would later be used in the HITL simulation.

The tabletop was organized into two parts; the first part focused on initial UAM operations and the second part focused on midterm UAM operations. During the first part of the session, SMEs were asked to provide feedback regarding the candidate airspace procedures and routes (for initial operations) that leveraged similar procedures used in today's NAS. In the second part of the tabletop, the same set of use cases were used to explore the proposed corridors and modified procedures tailored for midterm UAM operations. Both parts of the tabletop included separate hypothetical LOAs for which SMEs also provided feedback.

During the discussion regarding initial operations, one of the use cases explored how UAM aircraft may access the DFW terminal, which is located between two parallel runways (17R and 17L) (Fig. 4), through the published "Spine Road" helicopter route. Spine Road is at an altitude of 300 above ground level (AGL) (or 900 MSL). The DFW SMEs agreed that a route along Spine Road would be a feasible approach for UAM aircraft to access the DFW terminal since it is more than 2,500 ft apart from each runway, laterally.

Fig. 4. DFW Airport showing the location of the East and West Complexes, and location of runways, including 17R and 17L.

Similar to exploring the DFW terminal, some use cases explored how UAM aircraft may access the DAL terminal

(Fig. 5) during initial operations. The routes and proposed airspace procedures were deemed challenging due to the need for UAM aircraft to cross runways upon arrival at a specified vertiport that is located on the airport's parking garage. Revision suggestions were provided by the SMEs for the proposed routes and airspace procedures. Among the feedback received, SMEs noted that UAM arrivals into DAL should cross the runway mid-field, whenever possible. Additionally, UAM departures should avoid flying in the opposite direction of traditional, non-UAM traffic. SMEs also pointed out that since UAM aircraft are flying above the approaches, the altitude at which they cross the runway should take downwash, referred to as induced flow in helicopter aerodynamics, and taxiing aircraft on the ground into consideration.

Fig. 5. DAL Airport showing the two runways 13R and 13L.

For midterm operations, which were discussed during the second portion of the tabletop session, the concept of corridors was well accepted in the Class Bravo Airspace. Ten corridors were proposed for midterm operations in the Dallas metropolitan area (Fig. 6). Corridor dimensions consisted of the following characteristics: 3,000 ft width, tracks that are 1,500 ft apart, and floor-ceiling dimensions of 400 ft to 600 ft AGL. Some corridors were at 1,600 ft MSL to provide deconfliction through design.

An analysis that was conducted by the NASA-Joby research team to assess frequency of encounters in the Dallas area was also shared with the SMEs for their feedback. The frequency of encounters were portrayed with historical tracks overlaid on the proposed corridor network [8]. SMEs agreed that the proposed corridors during midterm operations were feasible. They also agreed that modified procedures may be beneficial for scalability and reduced communication requirements between ATC and the on-board PIC. However, they noted that the implementation of the proposed corridors might be challenging under certain scenarios in which the UAM operation is in the vicinity of airport runways or in circumstances requiring UAM aircraft to cross active runways.

Fig. 6. Proposed candidate corridors for midterm operations in the Dallas metropolitan area.

Nine vertiport locations in the Dallas metropolitan area (Fig. 7) were identified for use in the HITL simulation. These were discussed as part of the process to review and refine airspace procedures and routes/corridors. Vertiport locations remained the same throughout the simulation for both initial and midterm UAM operations. Five of the nine vertiports were located within the designated Class Bravo Airspace, including DF120 (DFW Terminal Parking Garage), DF7 (Periphery of DFW), DF49 (Dallas Downtown), DF60 (Business Ramp at DAL), and DF61 (DAL Terminal Parking Garage). The remaining four vertiports were outside of the Class Bravo Airspace boundaries and included DF99 (Frisco Superdome), DF50 (Denton), DF00 (AT&T Stadium), and DF70 (Garland).

Fig. 7. Locations of the nine vertiports identified in the Dallas metropolitan area for use in the HITL simulation.

B. *Tabletop Session 2*

NASA and Joby Aviation researchers incorporated the findings from the first tabletop in the preparation for the succeeding tabletop activity, which took place in June 2023. These findings included changes to proposed airspace procedures and routes/corridors for UAM operations.

Similar to the first tabletop, the second tabletop activity also aimed at refining and validating assumptions regarding the proposed candidate airspace procedures and developed routes/corridors. A broader group of stakeholders were invited to participate. Representatives from the FAA, National Air Traffic Controllers Association (NATCA), DFW Airport, and industry took part in the discussion, along with the four retired air traffic controllers who participated in the first tabletop exercise. This tabletop was seen by stakeholders as an opportunity to provide constructive feedback in preparation for the HITL simulation. It was also seen as a means to assess the communications workload for air traffic controllers handling UAM aircraft. The natural threshold for ATC workload in initial UAM operations was also considered as part of the discussions.

An assumption was made that operational tempo higher than those found in initial operations would warrant the need for new airspace procedures, infrastructure, and capabilities. Stakeholders also discussed multiple topics during the two-day tabletop session, including:

- Regulatory perspective concerning the waiver process for separation criteria in the Class Bravo Airspace
- Tactical separation
- Role of ATC as it pertains to the delegation of separation services in corridors under VFR and VMC
- Flying directions of the Spine Road route
- Minimum equipment requirements
- Workload thresholds

Feedback was also received regarding the proposed hypothetical LOA with a few stakeholders suggesting that aircraft performance, given the unique characteristics of eVTOL aircraft, should be considered when drafting an LOA.

Additional topics were also brought up by the attending SMEs. These included wake turbulence susceptibility of UAM aircraft, environmental (e.g., auditory, and visual noise) and community factors, and aircraft in-trail separation requirements were discussed. Other pertinent airspace operations, such as those conducted by air ambulance and police helicopters, that may affect UAM were also discussed. Based on the feedback received from the second tabletop, additional revisions and modifications were made to the proposed use cases and candidate airspace procedures.

C. *Shakedown HITL Simulation*

The final step in the development of procedures consisted of conducting a shakedown HITL simulation, which assessed the changes made to the airspace procedures following the two tabletop exercises. The shakedown HITL simulation was a week-long activity conducted in August 2023 at NASA Ames' FutureFlight Central (FFC) (Fig. 8), a two-story high-fidelity simulation facility that offers a 360-degree field of view [11]. Participating SMEs included the same four retired DFW air traffic controllers who participated in the preceding tabletop activities. The findings from the two tabletop activities were implemented in the revised candidate airspace procedures and routes/corridors that were used the shakedown HITL simulation.

Fig. 8. 3D model rendering of NASA Ames' FFC high-fidelity simulation.

The shakedown HITL simulation provided the NASA-Joby research team the opportunity to determine the appropriate density of UAM traffic during initial and midterm operations for "low" and "high" traffic conditions. Table I shows the 2x2 experiment matrix that was evaluated during the shakedown, which was later used during the AIS HITL. A total of four runs for each condition was examined, which resulted in a total of 16 counterbalanced runs. Each run was 45-minutes in duration. The initial use cases were conducted first followed by the midterm use cases.

TABLE I. EXPERIMENT MATRIX

Experiment Matrix		
	Initial Use Cases	***Midterm Use Cases***
Low UAM Traffic Density	Condition A	Condition C
High UAM Traffic Density	Condition B	Condition D

The shakedown also provided software developers the opportunity to debug any software issues in the simulation. Training materials and survey questions were also reviewed with the four returning SMEs/retired air traffic controllers for clarity and quality. The findings from this shakedown activity and the preceding efforts were used in preparation for the HITL simulation that was conducted in September 2023 [12].

IV. SUMMARY

As the world of aviation continues to advance and the popularity of the UAM concept grows, maintaining the safety and efficiency of the NAS remains a priority. The process to develop candidate airspace procedures for UAM operations in the Dallas metropolitan area included two tabletop activities and a shakedown HITL. These activities successfully provided the NASA-Joby research team with the opportunity to elicit essential feedback and knowledge from a broad group of SMEs with proficiency in the aviation field. The candidate airspace procedures, routes/corridors, and LOAs developed were well-received by those in attendance, and the input received allowed the research team to appropriately refine and revise as necessary. Safety and efficiency are key to the success of integrating UAM eVTOL aircraft into the NAS. Further research is needed to explore and evaluate many aspects related to the integration of UAM aircraft into the NAS, including off-nominal, or non-normal, scenarios. Communications between key operators (ATC, dispatch, PIC, PSU, vertiport manager, etc.) also needs to be explored to ensure operators receive and relay the necessary information needed to maintain safety of the NAS through airspace and operational procedures.

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