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Near Term Urban Air Mobility Use Cases in the Dallas Fort-Worth Area

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Ames Research Center

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This report is available in electronic form at

http://

Executive Summary

The National Aeronautics and Space Administration (NASA) is conducting research on airspace management and flight procedures concepts for Urban Air Mobility (UAM). A series of collaborative meetings between NASA and Joby Aviation, informed by Federal Aviation Administration (FAA) and Dallas Fort Worth (DFW) Airport subject matter experts, spanned several years and developed five use cases for operations in the DFW area. This report describes how UAM aircraft could navigate between vertiports within a region with a high volume of conventional air traffic in the neighboring areas and provides recommendations for introducing UAM operations at DFW. The objective of this effort is to evaluate the extent to which UAM flights are possible in the current National Airspace System and identify whether existing approaches to expanded operations will work for UAM.

The five use cases were developed to include flights operating in both controlled and uncontrolled airspace. Some use cases involved flights departing from uncontrolled airspace, transiting controlled airspace, and arriving near a major airport. One use case involved repositioning a flight from a major airport like Dallas Love Field to the downtown area. Another use case focused on an aircraft malfunction requiring a diversion. The use cases covered issues that would need to be addressed to enable early implementation of UAM operations.

A challenge identified during the development of the use cases is the potential for an increase in air traffic controller (ATC) workload due to the requirement to grant a clearance to enter Class B airspace and manage aircraft in that airspace. The tower controller must provide services according to the type of airspace, aircraft, and operating rules within their scope including separation services, traffic and safety advisories, handoffs, and beacon code assignments. Existing tools such as Letters of Agreement (LOAs) can be created to define specific procedures and reduce controller communications. These LOAs would need to follow FAA processes such as safety risk management and be compatible with any existing LOAs.

Alternatively, a universal communications (UNICOM) area was proposed within Class B airspace over the Dallas Downtown area where many vertiports may be in close proximity. This area would have a common traffic frequency used by the pilot to maintain situation awareness and manage separation without involving ATC. This would reduce ATC workload by limiting the need for voice communication. Finally, it was suggested that a dedicated helicopter controller position may help serve larger numbers of all types of vertical takeoff and landing aircraft in terminal airspace to avoid placing increased workload on other controllers.

The proximity of UAM routes to conventional traffic may cause challenges for traffic separation. The routes that are used to get to operating locations, particularly existing airport infrastructure, cannot always be placed far enough from the routes used by today's aircraft. New flight procedures for both existing and new operations could help to keep aircraft nominally separated without tactical mitigations, an approach requiring an airspace safety analysis and potentially additional training for pilots and ATC. New or updated routes may be specified to accommodate the types of operations being introduced, similar to the goals of the FAA's helicopter route chart program. The participants discussed the potential for these airspace organization and procedure changes to remove constraints related to traffic separation, but further study is needed to develop solutions for specific operating areas.

Traffic management challenges may need to be overcome as the number of operations increase in comparison to the current day. For instance, helicopter flights in Class G and E airspace under visual flight rules in visual meteorological conditions may occur today without any ATC interactions. Increases in the tempo and density of operations in such airspaces may require new procedures, training, technologies, or airspace constructs. Although traffic tempos were not a focus of the use case development, they were a common topic of discussion among the developers of the use case. Understanding the applicability of different solutions to achieving certain throughput levels should be an area of future research.

Discussions among the developers of the use cases indicated that certain methods of accommodating new operations should have beneficial effects on scalability and safety, though each method is associated with a different level of effort. An LOA can greatly reduce pilot-ATC communications for some routes to enable relatively high traffic tempos and they can be implemented quickly compared to other methods, but they are region-specific solutions that may be challenging to generalize across the nation. UNICOM areas are effective at reducing ATC workload but shift the burdens of separation to pilots in a way that is difficult to scale. Finally, airspace may be redesigned to improve safety and reduce ATC workload through the regulatory process. Each of these methods will be discussed here along with their potential benefits and drawbacks.

A common recurring theme in the discussions was that, even though near term UAM operations are possible without any changes to rules or policies, controller workload, the ability to efficiently interact with existing airport traffic, and methods of handling increases in the number of operations are high-priority areas of study. Further research on early UAM operations could focus on how to manage clearances in and out of controlled airspace, employ a UNICOM area, use beacon codes, create an LOA to reduce demands on ATC, provide separation in controlled airspace, design and define UAM routes that are separated from legacy traffic, and manage contingencies. Both fast time and real time simulations with humans in the loop are suggested for exploring solutions to these research questions.

Introduction

Urban Air Mobility (UAM) is a mode of flight that could supplement today's ground transportation systems and existing helicopter operations that are limited due to costs and other factors such as noise [1,2]. In this paradigm, UAM aircraft would carry passengers and cargo safely and efficiently in urban areas using a new kind of aircraft. The long-term vision for UAM is expected to improve mobility for the public, alleviate road traffic, reduce trip time, and decrease strain on existing public transportation networks [3]. Various challenges exist to fully realize this vision of UAM operations. These include integration with existing airports and airspace, vehicle design and certification, and community acceptance. Careful consideration of these issues and their relationship with the National Airspace System (NAS) can help ensure that they will not constrain the growth of the UAM industry.

Electric vertical takeoff and landing (eVTOL) aircraft are being developed that already have sufficient payload, speed, and range to efficiently move people within the urban environment, such as to and from airports. Some of those aircraft manufacturers, such as Joby Aviation, are actively working through the certification process, with the first certification expected as early as 2024 [4]. Anticipating a significant increase in the number of aircraft operating in urban airspace, both the Federal Aviation Administration (FAA) [5] and National Aeronautics and Space Administration (NASA) [6] have developed concepts of operations (ConOps) describing how UAM operations will be handled, starting with initial operations to a long term, highly scaled, and autonomous future.

Part of NASA's UAM research is focused on creating and evaluating airspace concepts and procedures to support near and far-term UAM operations. The NASA UAM Subproject (under the Air Traffic Management-eXploration Project) and Joby Aviation are working together to identify requirements and propose solutions for managing UAM flights. The effort discussed in this paper assumes no major changes to the NAS and considers what constraints may be encountered under different operational scenarios. The scenarios, approach, and discussions from these collaborative sessions are described in this document.

Background

Considerations for airspace and procedures are integrated into an evolutionary framework for UAM [7]. This framework includes scheduling, separation, contingency response management, and concepts for mature UAM. Several principles have been proposed to guide the development of solutions that minimize constraints to the growth of UAM [1]:

1. Does not require additional ATC infrastructure
2. Minimizes impact on ATC workload[1]
3. Minimizes impacts to operations of traditional airspace users[2]
4. Meets appropriate safety thresholds and requirements
5. Allows for scalability
6. Allows flexibility where possible and structure where necessary

Following these guidelines, NASA has been researching UAM operations using both fast time and human-in-the-loop simulations. The first experiment in a series of studies conducted at NASA Ames Research Center evaluated the use of current-day helicopter routes and communication procedures for UAM flights [8]. This use case development was conducted in collaboration with Uber Elevate (now Joby Aviation) who reviewed the origin/destination pairs used for the study and provided potential business routes where available. Three different levels of UAM traffic were tested in simulations that emulated North Dallas area airspace. The current-day helicopter routes were modified to separate them from traditional traffic and a Letter of Agreement (LOA) was introduced in some of the test conditions to reduce verbal communications.

The research hypothesized that the modification of the routes and the introduction of the LOA would not increase controller workload and communications. There were three test conditions: Baseline without LOA, Current Routes with LOA, and Modified Routes with LOA. When the average time spent communicating was collapsed across all controller positions, it was determined for the Baseline Condition that the controller participants spent about 55% of the time communicating. For the other two conditions, the time spent was 44% and 46%, respectively. These results indicated an approximate 20% reduction in percentage of time communicating under the LOA conditions when compared to the Baseline Condition.

Another analysis of the same study [9] examined the number of UAM flights controllers could manage under the same three conditions as above. The number of UAM flights that the controller could handle improved from the conditions that used the current routes to the Modified Routes with LOA. A similar result was seen for the percentage of flights managed of those planned for that sector. The Modified Routes with LOA allowed one group of controllers to handle almost 90% of the UAM flights that were planned versus about 70% using the Current Routes with LOA condition.

This study also showed that the design of UAM routes should consider the proximity and configuration of airports in the vicinity of the routes (such as approach and departure paths and

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[1] The original principle was to “not impose increased workload on ATC”, but research has shown that some increase is inevitable. The principle has been rephrased to minimize the increase.

[2] The original principle was to “not restrict operations of traditional airspace users”, but research has shown that some changes are inevitable. The principle has been rephrased to minimize the impact.

direction of flow of traditional traffic) [10]. It was recommended that through careful route planning, UAM traffic could circumvent concerns such as noise and contingency management by avoiding congested or heavily populated areas and minimizing route segments that go through several sectors or transit Class B airspace (which creates additional pilot and controller workload).

Discussions with subject matter experts (SMEs) identified a preference for routes with two-way, altitude-separated traffic for simplified traffic management. The SMEs also suggested reducing the length of routes where possible for energy conservation and avoiding areas that are frequently subject to Temporary Flight Restrictions. They also recommended creating UNICOM areas within controlled airspace over the Dallas Downtown area to help reduce controller workload. A UNICOM area is a non-government communication facility (universal communications station), which provides airport information at certain non-towered airports. Locations and frequencies of UNICOMs are generally shown on aeronautical charts and publications and have a Common Traffic Advisory Frequency (CTAF) radio system. This common frequency is used by pilots to maintain situational awareness and manage separation at non-towered airports.

The next experiment [11] was an engineering evaluation performed in collaboration with Uber Elevate to investigate whether NASA's Unmanned Aircraft Systems (UAS) Traffic Management (UTM) architecture could be applied to UAM operations in the far term. It also evaluated whether the data exchange between multiple operators as planned under UTM is adequate for UAM in shared airspace.

NASA and Uber Elevate applied the UTM paradigm as implemented in Technical Capability Level-4 (TCL-4) to UAM operations. The main premise of the UTM architecture as defined in the UTM Concept of Operations (ConOps) was to submit operational volumes where the small UAS planned their operations below 400 ft. The UAS Service Supplier (USS) submitted the operational volume and detected potential conflicts between aircraft.

The study investigated three situations in which two operators conducted flights that shared traffic intersections and merge points. The UAM operators utilized the TCL-4 implementation of the UTM architecture and explored submission of tracking along routes and conformance monitoring to those routes. Strategic deconfliction was explored for the flights where pre-departure delay was applied to de-conflict the UAM flights from each other at crossing and merge points.

While testing strategic deconfliction, it was found that a balance is required between when the flight details are shared among operators and the size of the airspace volumes at the crossing points. The study uncovered that the implementation of specific services can have a considerable positive impact on the efficiency of the system. Further, the study also found that using volumes for trajectory planning for UAM operations results in inefficiencies and excessive delays and recommended the use of 4D trajectories rather than volumes.

Several ConOps have been developed to address the challenges for integrating UAM aircraft into the NAS. The FAA published a UAM ConOps [5] that introduces new airspace technology such as the Provider of Services to UAM (PSU) and new structures (corridors). This document includes a description of low tempo UAM traffic flows consistent with current rules and regulations conducted by certified electric aircraft and conventional helicopters. The airspace structure is based on existing helicopter routes, helipads, policies, and regulations as well as present-day ATC services. At initial levels of UAM traffic, novel airspace structures or procedures (e.g., corridors) may not be needed. As the number of flights increase, UAM may require changes to the governing FAA policies and regulations augmented by Community Based Rules, new UAM airspace designs, and increased use of automation [5]. UAM flights may occur within defined corridors between UAM aerodromes (a location from which UAM flight operations depart or arrive, also referred to as vertiport in this document) and will have specific aircraft performance requirements.

Under current day visual flight rules (VFR) in Class B, ATC is not required to provide separation services between VFR and instrument flight rules (IFR) helicopters. However, they are required to provide separation between helicopters and other VFR/IFR aircraft and issue traffic advisories and safety alerts to IFR/VFR helicopters [13]. The FAA ConOps proposes that ATC will not provide tactical separation services to UAM flights within corridors. It is unclear if ATC would still communicate with the UAM flights inside the corridors and provide them traffic advisories. In the near term, tactical separation may remain with the onboard pilot and ATC communications may be required. In future, as volume of operations increase and operations utilize rules to expand beyond VFR in poor visibility conditions, tactical separation may be allocated to UAM operators and third-party service providers. The assumptions made in the studies [8,9] completed at NASA were consistent with the tenets of the FAA ConOps v1.0.

NASA also developed a vision for UAM [6] that is focused on a more mature end-state system. NASA identified five pillars or components of an organizational framework to achieve success for UAM. These include community integration, airspace and fleet operations management, individual aircraft management and operations, aircraft development and production, and airspace system design and implementation. NASA also defined seven cross-cutting barriers to achieve each pillar. These include safety, security, affordability, noise, automation, vertiports, and regulations/certification. This vision document identified success criteria for each pillar along with the barriers to each and included a comprehensive, top-down guide for integrating UAM into the NAS in the near term while considering far term requirements.

To create a common framework of reference, NASA established the UAM Coordination and Assessment Team that generated a model for how UAM operations may evolve. The framework describes a UAM Maturity Level (UML) Scale (see Figure 1) [7,12]. Each level of the scale is tied to specific stated goals and defining characteristics. There are three overall stages including “Initial State,” “Intermediate State,” and “Mature State.” UMLs falling under “Initial State” represent near-term UAM operations. UML-1 is defined as “Late-Stage Certification Testing and Operational Demonstrations in Limited Environments” and covers testing prior to commercial flights. The second stage under the “Initial State,” known as UML-2, is described as “Low Density and Complexity Commercial Operations with Assistive Automation.” In this “Initial state” the environment has low density and complexity traffic with favorable weather conditions in a limited number of “early adopter” locations with reliance on assistive automation.

This report focuses on near term operations that utilize current day routes and procedures. However, planning for future UAM integration into the NAS in the intermediate and mature states is also considered.

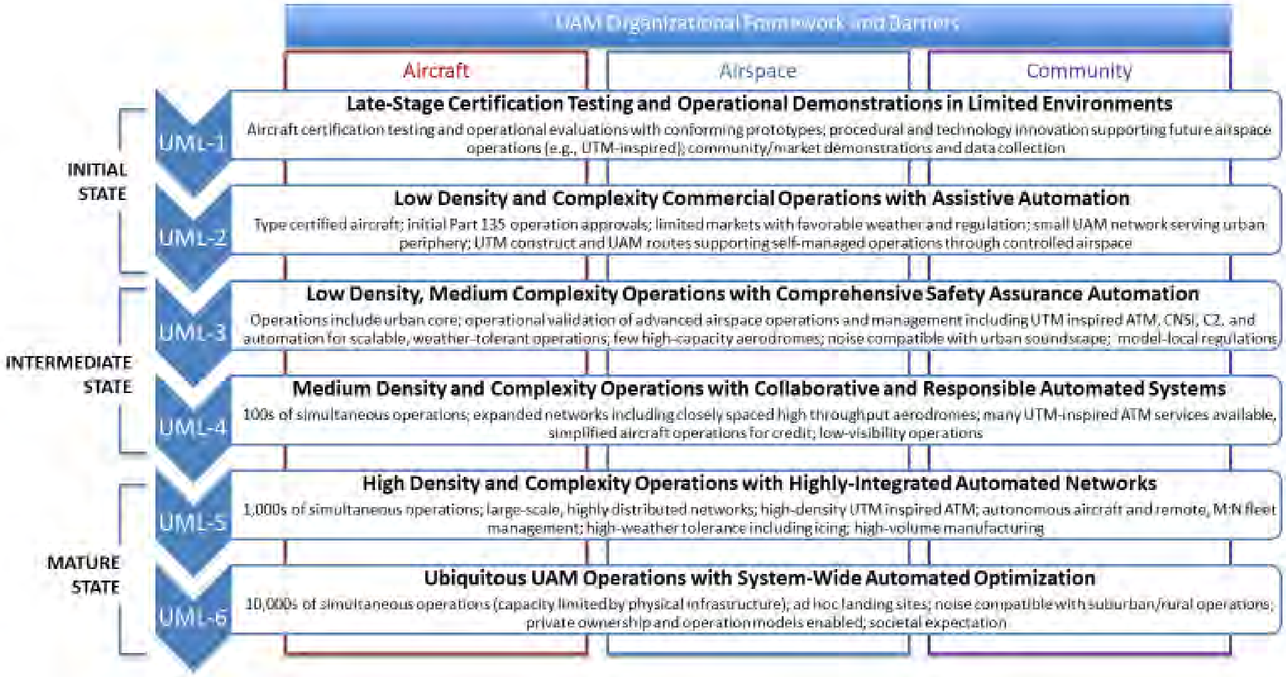


Figure 1. UAM Maturity Levels (UMLs)

Approach

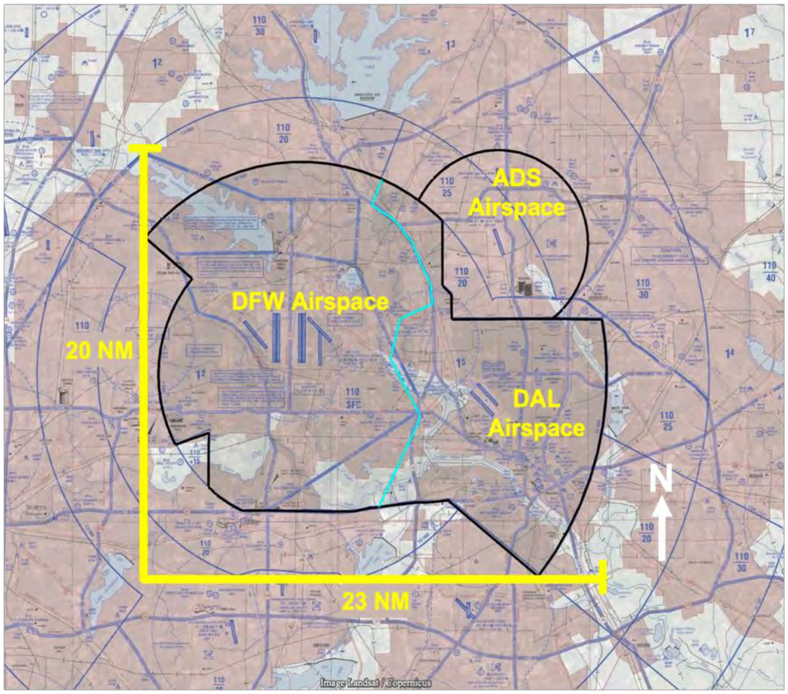
The NASA UAM Subproject in collaboration with Joby Elevate identified near-term use cases, routes, procedures, and tools available in the NAS to enable initial UAM. NASA worked in partnership with Joby Aviation, which provided perspectives on the business case along with performance information for the Joby eVTOL. The collaboration leveraged SMEs from the FAA, local air traffic facilities, and DFW airport who provided feedback. Multiple discussions were held with the SMEs to validate and explore the near-term use cases.

The use cases described here are not meant to cover a broad or exhaustive range of possibilities but are intended to demonstrate how the airspace could be used by UAM aircraft in the near term with the anticipated capabilities and performance characteristics of the aircraft. This report reviews the conceptual work and key aspects of the use case development and analysis. This section describes how airspace for UAM operations that would require the least ATC interaction was identified, assumptions made for the use cases, proposed tools such as LOA and UNICOM areas, as well as roles and responsibilities of the different actors.

Dallas Airspace

The greater Dallas Fort Worth metropolitan area was chosen as the airspace for this research. It includes three major airports of interest for UAM operations including Dallas Fort Worth (DFW), Dallas Love Field (DAL), and Addison Airport (ADS). All airports in the DFW area are at about 600 ft above mean sea level (MSL). The terrain impacts the altitude depicted to controllers. For example, flights at 500 ft above ground level (AGL) show as 1,100 ft (MSL) on a terminal radar display. Both DFW and DAL are in Class B airspace, whereas ADS is Class D airspace. Additional surrounding airspace includes Classes G and E.

In Figure 2, DFW Tower, DAL Tower, and ADS airspace are depicted. In total, the DFW area airports feature four approach streams and four departure streams with DFW airport having the greatest number of traffic flows (Figure 6). Between years 2009 and 2017, average operations for commercial aviation operations at DFW alone ranged from 2,135 to 2,369 aircraft per day.



Maps Data: Google Earth 2019, Image Landsat/ Copernicus

Figure 2. DFW, DAL, and ADS airspace.

To develop the use cases, a set of origin and destination points within the DFW airspace was chosen based on possible business case options and forecasted demand for UAM operations provided by the industry partner, Joby Aviation. The use case development began with a simple route that could possibly be flown under current day VFR in Class G/E airspace without the need for ATC interaction. The other use cases increase in complexity with one involving a non-emergency diversion due to an equipment malfunction.

The UAM routes for the use cases were placed within airspace that was largely deconflicted from traditional air traffic at varying altitudes as shown in Figure 3. Standard Instrument Departures (SIDs) and Instrument Approach Procedures (IAP) were used to identify the airspace demands of traditional traffic around large airports (Figures 4 and 5). There is also an FAA requirement that ATC must provide wake turbulence advisories to aircraft with less than 2,500 ft lateral or 1,000 ft vertical separation [13]. These criteria were applied to identify areas where UAM operations in Class B airspace would be separated from SID and IAP and this led the first iteration of the airspace for UAM operations.

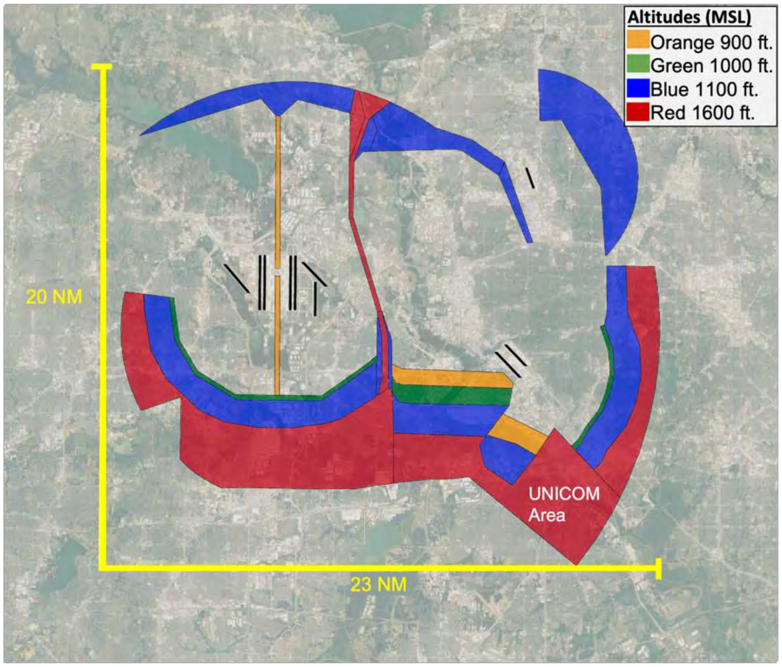


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Figure 3. Class B and D airspace designed to minimize interactions with IFR aircraft.

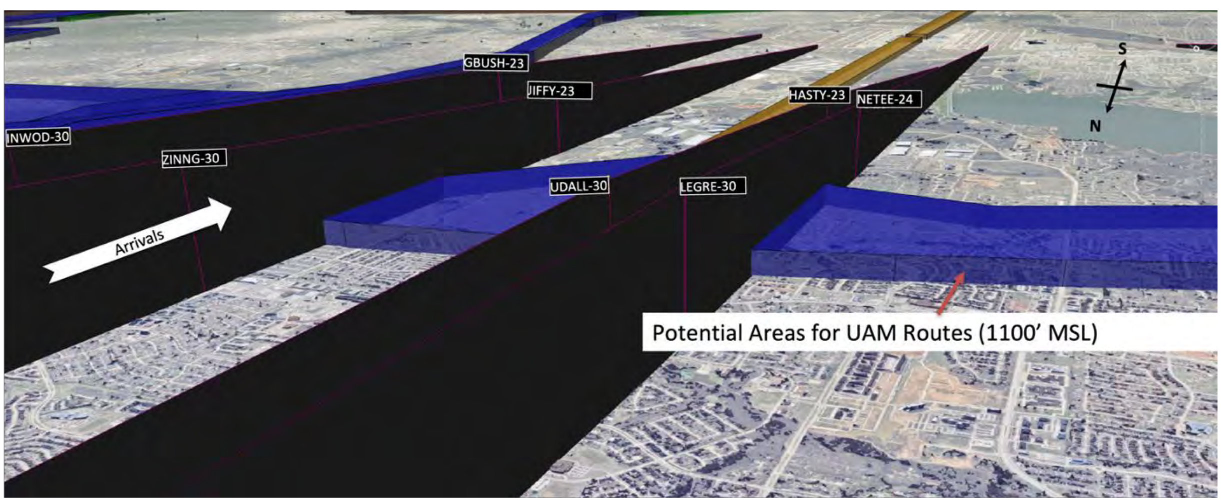

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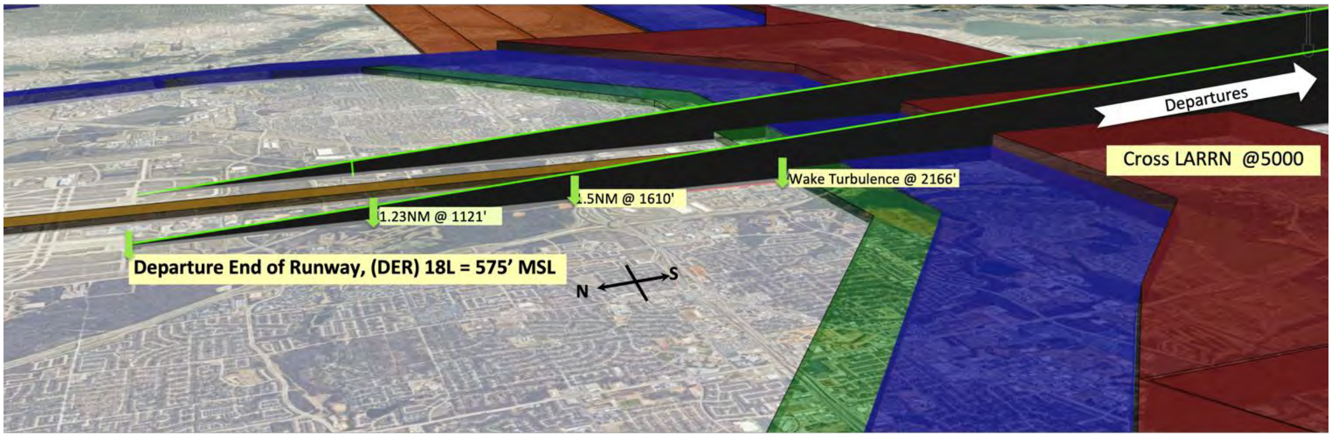
Figure 4. DFW arrival procedures. Fixes and altitudes for the expected path of 18L arrival traffic.

This airspace was not planned to be segregated from other users. The objective was to have the least amount of conflict with legacy traffic so that it minimized ATC interactions. Figure 5 shows the approach patterns into DFW in the South Flow and the altitude restrictions at different waypoints (e.g., NETEE is 2,400 ft MSL). The airspace identified for UAM operations at 1,100 MSL is about 1,000 ft below what the legacy flights are expected to fly (e.g., 2,300 ft MSL at HASTY or 2,400 ft MSL at NETEE). Similarly, Figure 5 shows the expected altitude the legacy flights will fly from the departure end of the runway in South Flow. The green band of airspace identified in Figure 5 shows that UAM flights would be at 1,000 ft MSL while the legacy flights would be at 2,166 ft MSL at that location, which provides 1,000 ft separation between the legacy and UAM flights.

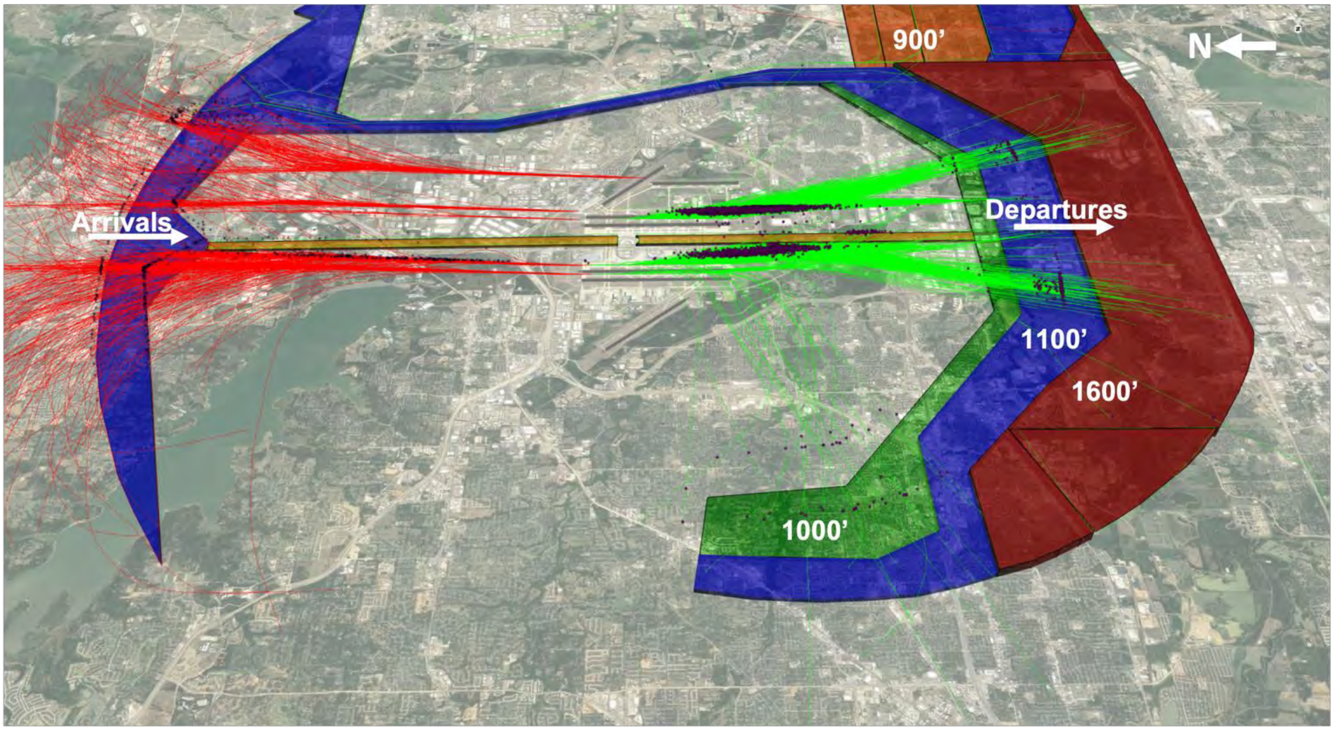


Maps Data: Google Earth 2019, Image Landsat/ Copernicus

Figure 5. DARTZ Departure. DARTZ departure procedure depicts the expected path of 18L departure traffic.

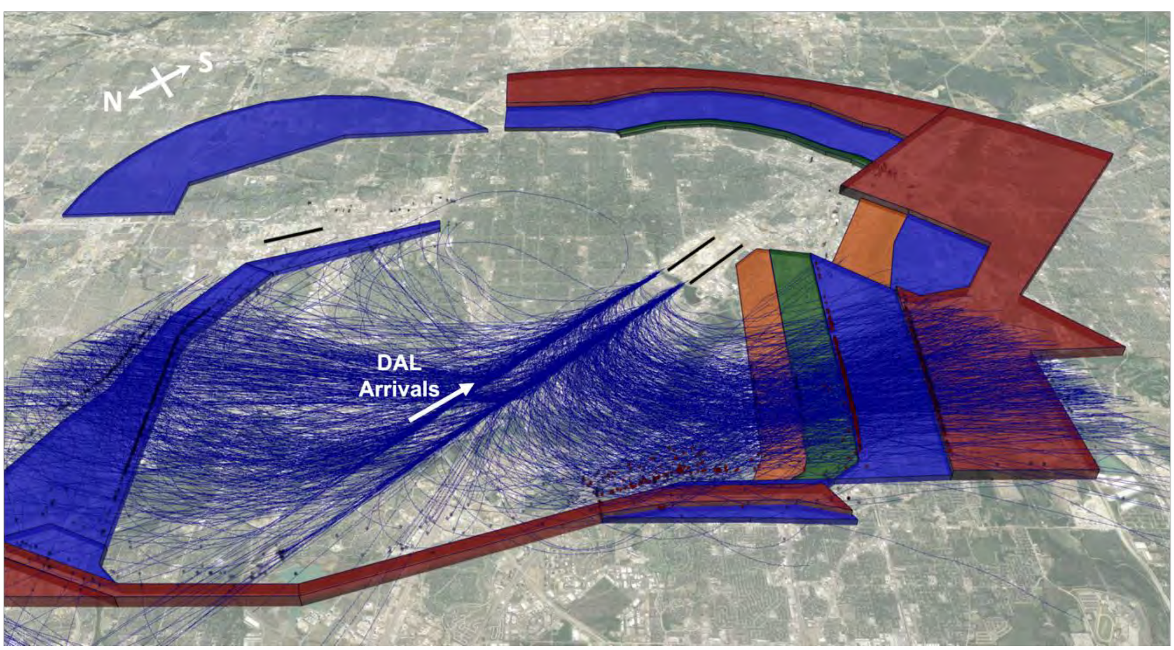
The airspace was further evaluated using historical track data (see Figures 6 and 7) to ensure that most of the UAM flights were outside the wake turbulence advisory criteria. For the purpose of these uses cases, all the UAM operations were planned to fly at 1,000 ft AGL. The result was to identify airspace for UAM flights that are separated (about 95% of the time) from legacy traffic (see Figure 4). The methodology for identifying this airspace is explained in more detail in [14].

A UNICOM area is a non-government communication facility which provides airport information via CTAF at certain non-towered airports, including parking information, the availability of pads, and other safety, logistical, and situation awareness data. The pilot is able to communicate on the UNICOM common frequency before they enter the UNICOM area and while they are inside the area to coordinate with other traffic. A candidate UNICOM area is defined by the purple shaded area in Figure 3 as part of the use case development. It is a relatively small portion of the DFW Class Bravo surface area identified as possible airspace that may be used by flights without requiring ATC communications or clearances. For the purpose of this paper, the UNICOM (area) refers to the area defined over Dallas Downtown (see the purple area in Figure 8).



Maps Data: Google Earth 2019, Image Landsat/ Copernicus

Figure 6. DFW arrival tracks in green and departures in red.



Maps Data: Google Earth 2019, Image Landsat/ Copernicus

Figure 7. DAL arrivals. Tracks are shown in blue.

Assumptions

For this research, it was assumed that DFW and DAL Airports are in South Flow (they are in the south configuration 75% - 80% of the time) and the UAM pilots operate under VFR. The vehicles used for these early UAM flights will have a pilot onboard. Vertiports (locations from which UAM flights depart or arrive) are assumed to be available for public use and shared by different operators. However, these use cases did not explore the interactions between multiple UAM or vertiport operators. All operator roles are assumed to be fulfilled by a human.

It is assumed that UAM aircraft will likely follow well-defined arrival and departure procedures using flight management systems that ensure high navigational accuracy and adherence to procedures. The eVTOL aircraft discussed in this study are likely to be certified as a Part 23 fixed-wing airplane. This assumption has implications for airspace design and the altitude that the eVTOLs will be allowed to fly over populated areas. Also, we assume the eVTOLs to be equipped with Automatic Dependent Surveillance – Broadcast (ADS-B) In and Out as well as Mode C transponders.

The operational tempo for these use cases was assumed to be low in volume, defined relative to current day helicopter operations in the area. Low volume UAM operations are likely to be equivalent to or less than the current level of helicopter traffic. Thus, scalability is discussed while keeping the limitations of the current day procedures in mind.

Letter of Agreement (LOA)

As part of the approach, current tools that could be used for near term UAM operations were proposed including an LOA. An LOA was suggested as a temporary, near-term local solution to reduce ATC communication with UAM flights and limit controller workload. LOAs can reduce verbiage, precisely define the available routes, and separate the routes vertically from each other. An LOA may have provisions for a flight to have a pre-assigned beacon code. Route codes or names for flights flying between the same origin and destination pairs may be defined. The route codes described would be used by the signatories to the LOA.

The UAM operators, local FAA facilities, and airport are generally signatories to the LOA. LOAs can also define procedures for entering Class B airspace as well as landing and departure advisories, which could help reduce the radio traffic required for entry into Class B, C, or D airspace. The routes and airspace defined in the LOA are available to both signatories and non-signatories (although the procedures in the LOA are not available to the non-signatories). The proposed LOA enables early UAM operations in a local geographical area while allowing for information gathering to determine the procedural changes that might be needed to support future operations. Any proposed LOA must go through the FAA's required safety processes prior to their approval and would need to be compatible with existing LOAs, local procedures, and practices.

Roles and Responsibilities

For this research effort, the roles included in the description of each use case are air traffic controller, UAM operator, vertiport operator, and the pilot in command (PIC). Each use case describes the roles and responsibilities for each phase of flight. The roles are defined in the following sections.

Air Traffic Controller

The FAA has regulatory authority over all airspace operations including UAM flights and maintains a safe and equitable operating environment. Air traffic controllers would manage UAM aircraft much like helicopter traffic when they are operating in Class B, C, and D controlled airspace under VFR. ATC can also provide services to Class E (also controlled airspace) at the request of the UAM pilot and traditional roles and responsibilities are not expected to change for legacy traffic. There are two different tower controllers described in these use cases. The local controller actively manages the arrivals and departures at an airport whereas the ground controller handles aircraft on the airport surface (e.g., taxiways).

UAM Operator

UAM operators (assumed to be Part 135 operators) manage all facets of their enterprise including regulatory compliance. They are responsible for their fleet and individual aircraft management, coordinating the schedule, and negotiating with vertiport managers for access to landing pads. The operator obtains current weather and air traffic conditions from existing approved aviation sources.

A flight follower or UAM dispatcher, an agent of the UAM operator, prepares flight intent information in the form of an operation plan (similar to a flight plan), which is not filed with the FAA. The flight follower also collects and evaluates weather information, manages aircraft weight and balance, calculates energy (fuel) required and energy reserves for each flight, monitors the flight to ensure route and schedule conformance, delays or cancels the flight if needed, updates the pilot on weather or operation plan changes, manages aircraft maintenance, and shares data with other entities, as required. In Part 135 operations, the certificate holder (or operator) has responsibility for operational control. This is usually delegated to the PIC and the flight follower does not share operational control, as they do in Part 121.

Vertiport Manager

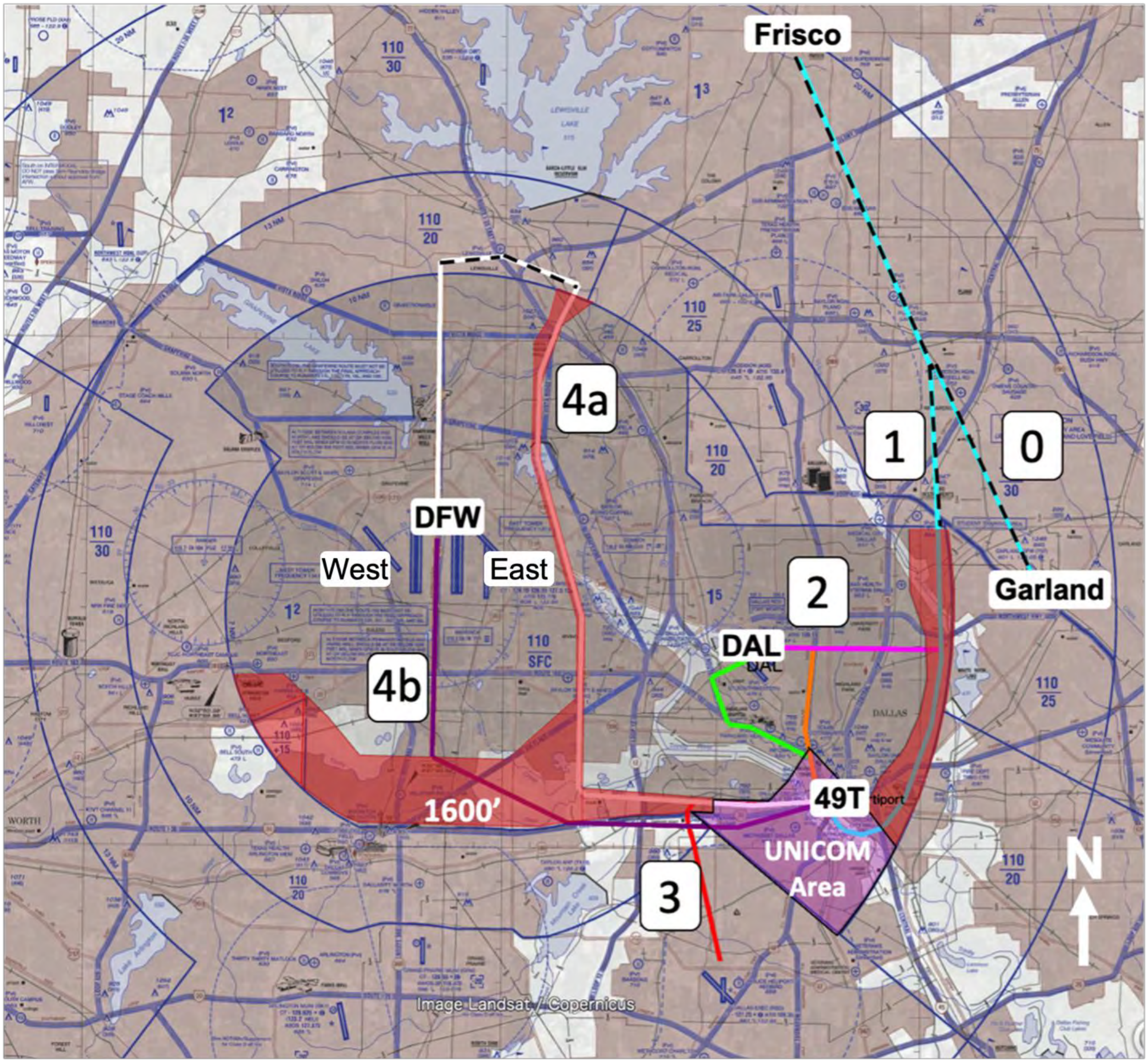
A vertiport is an area designed specifically for UAM aircraft to take-off and land. The origin and destination locations in the use cases show potential vertiport locations. Some are existing heliports, such as Garland (T57) and 49T in the Dallas Downtown area. Passengers embark and disembark at the vertiport and aircraft are charged there and can receive limited maintenance. The vertiport manager manages the scheduling of vertiport resources including turnarounds and pad availability for inbound and outbound traffic. They also provide resource information for UAM operations (e.g., pad availability) but do not offer tower-like ATC services. Most of the vertiports may operate like uncontrolled towers where pilots are responsible for safe takeoffs and landings with the exception that they may coordinate with the vertiport manager.

Pilot in Command

The PIC is the person aboard the aircraft who has the final authority and responsibility for the operation and safety of the flight as defined in 14 CFR Section 1.1. It is assumed that the PIC follows the aviate, navigate, and communicate task priorities. The PIC's primary responsibility is to fly the aircraft using flight controls to direct its attitude, airspeed, and heading. The PIC's second priority is to navigate (have awareness of the current position, and the planned route of flight). The PIC's third priority is to communicate as appropriate with ATC or others outside the aircraft. They are also assumed to follow the terms and conditions of the LOA described earlier.

Use Cases

Five use cases were created to explore the implications of initial integration of UAM flights into the Dallas metro area under VMC operating VFR with a PIC onboard. The first use case takes place entirely within Class E/G airspace. From there, the use cases build in complexity, including one instance of a diversion due to a possible equipment malfunction.



Maps Data: Google Earth 2019, Image Landsat/ Copernicus

Figure 8. Use Cases 0 to 4b. Red and magenta area on map depict areas for UAM operations that are procedurally deconflicted from traditional air traffic.

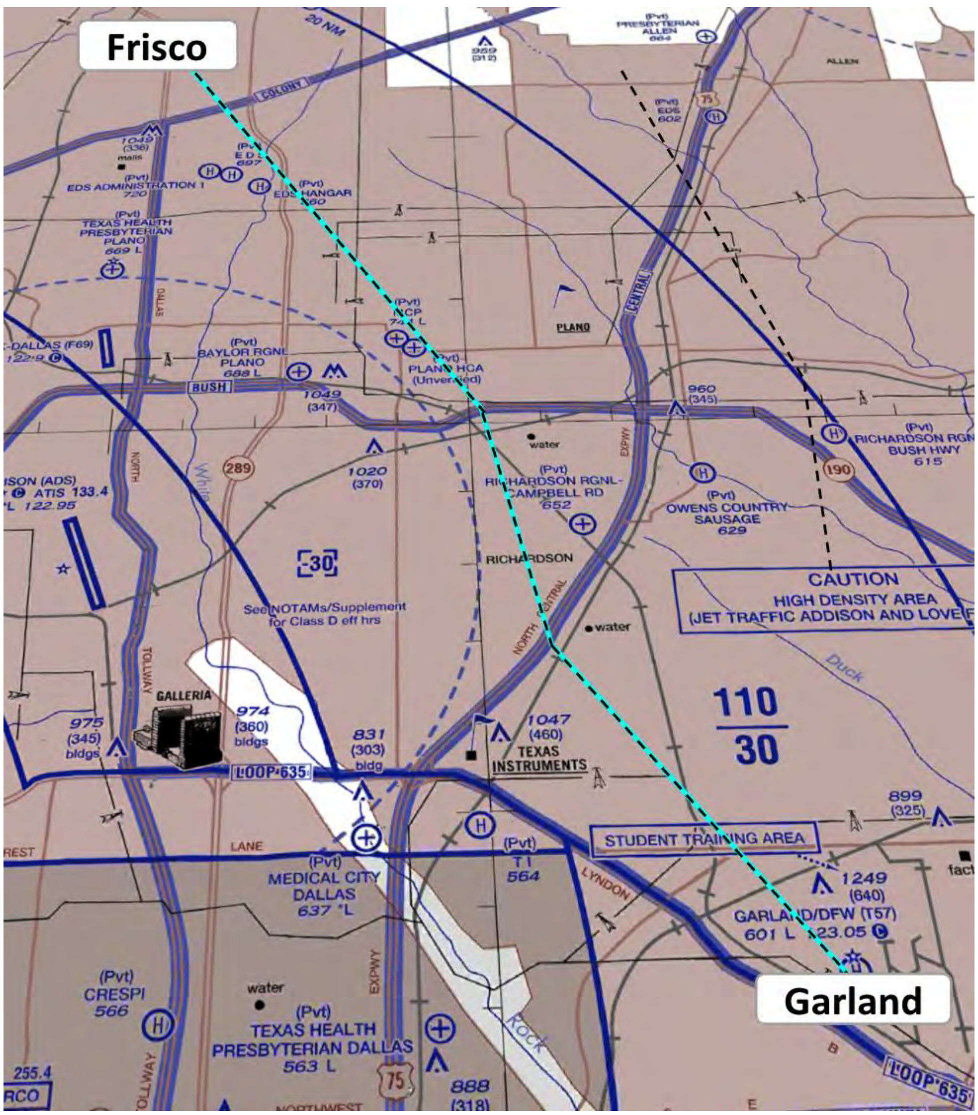
The use case routes with origin and destination points are depicted in Figure 8:

0. Use Case 0 describes a flight traveling a route from Frisco to Garland, Texas operating entirely within Class E/G airspace.
1. Use Case 1 describes a flight traveling from Frisco to Downtown Dallas, Texas, originating in Class E/G entering Class B.
2. Use Case 2 describes a flight that is repositioned from DAL airport to Downtown Dallas within Class B. The intent of this use case is to explore a company’s need to reposition aircraft to adapt to scheduling demands.
3. Use Case 3 describes a flight traveling from DAL to DFW, but the aircraft requests to be redirected in flight from within Class B to land at KRBD (Redbird) in Class D.

4. Use Case 4 describes two different flights traveling from DAL to DFW within Class B using the Spine Road, which is an existing helicopter route that runs through the middle of the DFW airport between the East and the West terminals.
   a. Use Case 4a is a flight traveling to DFW from the north on Spine Road in the same direction as the arrival traffic flow.
   b. Use Case 4b is a flight traveling on Spine Road in the opposite direction of the arrival traffic flow.

Use Case 0: Flights Operating Entirely Within Class E/G Airspace

This use case explores the least complex scenario of a UAM flight departing from a non-towered vertiport in Frisco, a city in the northern Dallas area, and arriving at the non-towered Garland Heliport (T57) (see Figure 9 for the en route portion of Use Case 0).



Maps Data: Google Earth 2019, Image Landsat/ Copernicus

Figure 9. Use Case 0 Route, Frisco to Garland.

Procedural Steps for Use Case 0

Pre-Flight

In the pre-flight phase, the flight follower reviews the proposed operational day based on the reservations the company has received. The flight follower then confirms or modifies the flight routes while ensuring compliance with company policies, current Notice to Airman (NOTAMS), Automatic Terminal Information Service (ATIS) data and any other relevant information. The flight follower also reviews weather throughout the route network and passenger flow access to and from airports and vertiports. The flight follower reviews the schedule and the plans for the day and discusses them with the vertiport managers and the company coordination center. They may make network flow changes based on vertiport availability. The vertiport manager reports any infrastructure outages to the flight follower including unavailable parking, instances of charging station inoperability, etc.

The PIC reviews Part 135 operator's management application on their electronic flight bag (EFB) to confirm current tasking and aircraft assignment. The PIC also reviews daily flight information provided by the flight follower, which is linked to their EFB. This includes notes from Director of Operations or Chief Pilot, relevant reports, status of the day's vertiports, routes, diversions or alternate locations, weather briefs, NOTAMs, and airspace information. The PIC reviews the first assigned operation plan of the day including routing, diverts and expected charge requirements.

The PIC also confirms that the weather is appropriate for the flight as defined by company policies in the approved general operations manual. The PIC conducts a maintenance review by checking all previous PIC write ups, maintenance actions, open discrepancies, battery state of health, and additional diagnostic information via the Part 135 maintenance application on the EFB. The PIC reviews the state of the aircraft's charge to ensure adequate energy for the scheduled trip. They also sign the airworthiness document for the aircraft electronically via the Part 135 maintenance application.

The PIC then conducts a risk assessment by accessing the company's daily risk assessment product via EFB. They also assess the risks and hazards mitigation plan and conduct a preflight walkaround inspection of the aircraft.

Pre-Departure

Before starting motors, the PIC conducts in-cabin, pre-departure procedures including passenger briefing, if passengers are on board. Then, utilizing the EFB, the PIC sends the first route to the aircraft avionics and reviews it on the flight deck displays. The PIC also checks the takeoff window, via the flight log on the EFB, and the required battery's state of charge for the flight. The PIC then completes the pre-taxi checklist, receives the updated ATIS report specific to their planned route with altimeter setting, and ensures that the beacon code that is pre-assigned is set for radar identification.

Prior to starting motors or engaging the propellors the PIC signals the lineman to relay the aircraft's readiness and then starts the engines. The PIC then executes the taxi checklist, contacts the vertiport manager, and receives permission to taxi to the pad or the final approach and take-off area (FATO). The PIC signals the lineman to relay their readiness to taxi and starts taxiing to the FATO.

Departure

The PIC announces the intention to depart on CTAF, lifts to a 5 ft hover, and conducts system checks. After all checks are complete, the PIC transitions the aircraft to forward flight. The PIC ensures that the departure path is on the predetermined noise abatement/obstacle clearance heading and activates the autopilot after transition at the appropriate altitude. During this phase of flight, the flight follower begins to monitor the aircraft on the displays provided by the company to ensure that that they are meeting scheduled times and have the latest information regarding the flight.

En Route phase

During the en route phase of flight, the flight follower monitors the aircraft on and ensures that the flight is conforming to its route and schedule. The PIC is responsible for aviating, navigating, and communicating during the flight. The PIC monitors the locations of nearby aircraft by direct visual scan out the cockpit as well as an ADS-B In traffic display. The PIC conforms to the route conformance as defined in the operation plan on their EFB.

Approach and Arrival

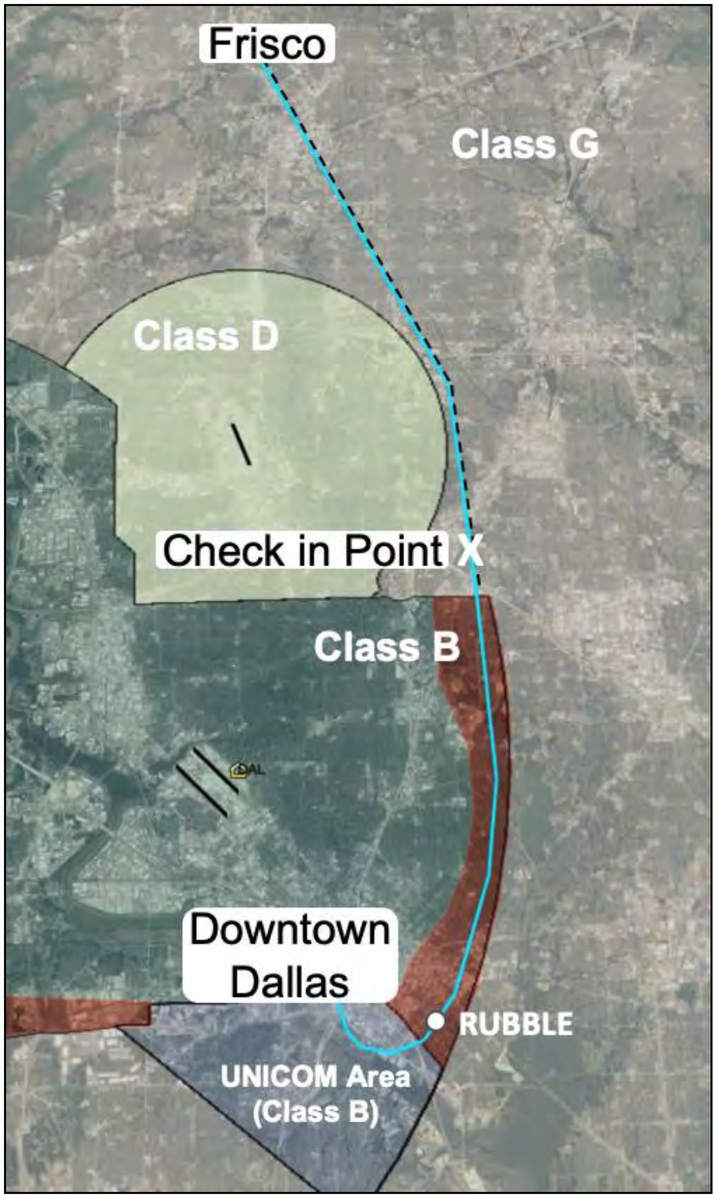
During the approach and arrival phases of flight, the PIC executes the arrival checklist and begins deceleration from cruise flight speed and announces the intent to land on CTAF. The vertiport manager acknowledges the PIC and provides a parking pad while managing all the scheduling of the inbound and outbound traffic to the vertiport. The PIC announces “turning on final” on CTAF prior to landing. In the post-flight phase, the PIC taxis to the parking pad and completes the post-flight checklist. The flight follower monitors the turnaround of aircraft, which includes dis-embarkment of any passengers, fueling/charging, and boarding for the next flight and addresses any issues.

Conclusions for Use Case 0

The main discussion points regarding the development of Use Case 0 were that operationally it is identical to a current-day VFR operation in Class G/E airspace, can be flown now without ATC interaction, and does not require any changes to existing airspace procedures, policies, or rules. Helicopter flights occur today and initial eVTOL UAM operations are likely to be conducted in the same way. In the event of the certification of the eVTOL as a fixed wing aircraft, there are implications for the altitude it can fly or its landing locations that need to be explored given existing policies, rules and regulations.

Use Case 1: Flight from Class E/G to Class B Airspace

This use case describes a flight departing from Frisco in Class G airspace and arriving at the Downtown Dallas vertiport (49T), which is within the UNICOM area in Class B airspace (see Figure 10) for the en route portion of Use Case 1). This use case differs from Use Case 0 in that it requires a clearance into Class B airspace. An LOA is introduced as a means for reducing ATC communications.



Maps Data: Google Earth 2019, Image Landsat/ Copernicus

Figure 10. Use Case 1 Route, Frisco to Downtown Dallas.

Procedural Steps for Use Case 1

Pre-flight, Pre-Departure, and Departure Phases

The Pre-flight, pre-departure and departure phases are the same as described in Use Case 0.

En Route Phase

During the en route phase of flight, the flight follower continues to monitor the flight, while the PIC is responsible for aviating, navigating, and communicating. As per the procedure in current day VFR operations, the PIC requests a clearance to enter Class B airspace a few miles from the Class B boundary (e.g., at the check-in point marked in Figure 10). The request for entering Class B requires that the PIC provide the entire route they plan to fly in their radio request. The flight is assigned a beacon code by the controller, and DAL Tower requests the PIC to radar identify themselves using 'IDENT' (identification using a transponder), which the PIC complies with. This allows the controller to identify the flight, verify Mode C, and locate it on their radar display. The controller provides a Class B clearance, which the PIC reads back.

To reduce ATC communications with the PIC, an LOA is proposed where the UAM flight would have a pre-assigned beacon code and route codes. Route codes or route names are used to pre-define the route in the LOA for flights flying between the same origin and destination pairs. The route codes would be used by the PIC when communicating with ATC. The route code has a pre-defined route associated with it that the pilot uses when requesting entry into Class B airspace at the check-in point (see Figure 10). In this LOA, the PIC is expected to switch to the UNICOM frequency at a pre-determined coordination point (e.g., RUBBLE) and contact the vertiport manager prior to approach and arrival.

Most of the current day communications required by these procedures could be removed by utilizing the LOA, which would pre-assign the beacon codes and define route codes for a given origin, destination, and relevant route. The LOA would specify predetermined Class B entry procedures, as well as landing and departure advisories. The identification of the flight by the local controller on their radar and the first check-in by the UAM PIC would be the only actions required between the controller and PIC when using the LOA, thus reducing communication and coordination required under current day procedures.

Approach and Arrival Phase

The approach and arrival phase for Use Case 1 is the same as Use Case 0, except that prior to entering the UNICOM area, the LOA requires the PIC to switch to the UNICOM frequency at a specified waypoint (RUBBLE). The PIC uses this frequency to contact the vertiport manager for their landing and parking information. The UNICOM frequency is also beneficial in that it allows for situation awareness of other pilots also flying in the UNICOM area. The post flight phase is the same as in Use Case 0.

Conclusions for Use Case 1

The main conclusions drawn from the discussion of Use Case 1 were that in part, like Use Case 0, it is feasible as a current-day VFR operation in Class G/E airspace, except that ATC interaction is required for entry into Class Bravo. This use case suggests utilizing an LOA as well as defining UNICOM areas to alleviate concerns with scalability and controller workload, but these are not required to fly in the current day environment. For this use case, a predefined coordination point close to the Class B airspace boundary was defined. However, it may not be possible for the PIC to get an immediate clearance to enter Class B airspace. In this situation, the UAM aircraft would have to remain outside of controlled airspace either hovering or flying a holding pattern, which has implications for battery reserves.

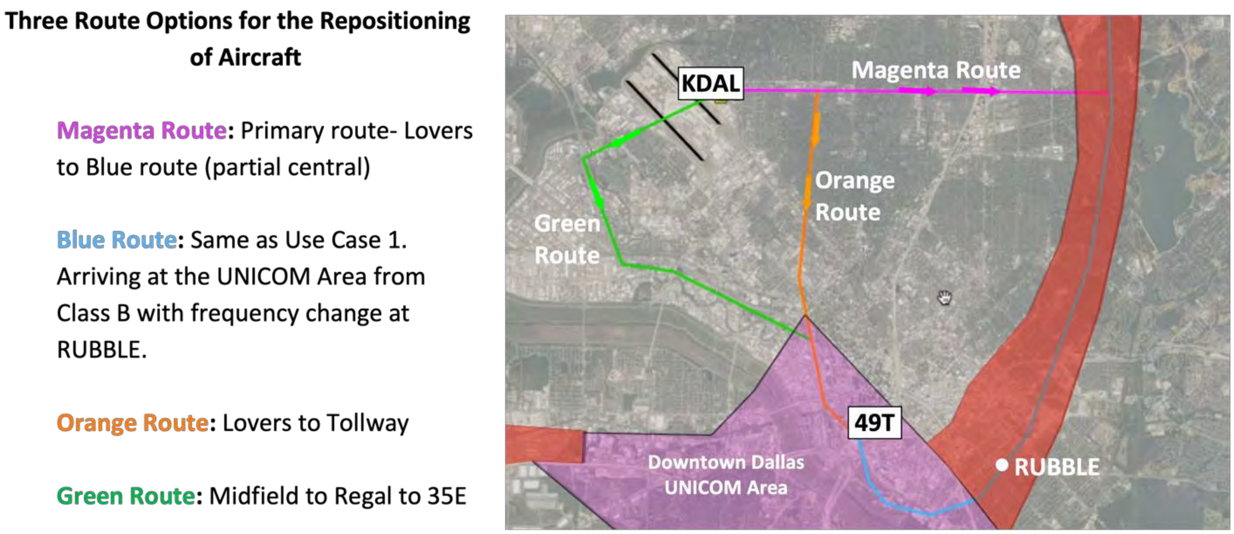
To allow for a potential delay in getting the Class B clearance, the predefined check in point prior to entering the Class Bravo should be placed at a sufficient distance from the Class B boundary to allow time for the handoff and communication. Many eVTOL operators would prefer not to hover to absorb a delay due to energy concerns and would instead use a holding pattern. The aircraft would maintain a low speed, (i.e., 40 to 60 kt) and fly a tight pattern. Aircraft may need special handling if there is a low energy situation, which is not expected to be a frequent occurrence.

The definition and use of the UNICOM area over Dallas Downtown is not a requirement to fly UAM in the current day environment. However, it has the potential to decrease controller workload since neither wake turbulence call outs nor separation from conventional, larger aircraft, would be required. The PIC would be responsible for “see and avoid” and utilizing any technology such as “detect and avoid” in advisory form in the UNICOM area. Several possible alternatives to a UNICOM area were also considered by the group including current day tools such as an LOA signed by all operators in that airspace, establishment of a special flight rules area (which could create a VFR corridor), or reclassification of the airspace over Dallas Downtown to Class E. Previous studies suggest that the introduction of an LOA may reduce overall controller workload but that other changes to rules or procedures may also be necessary for scalability [3]. An LOA is a local solution and changes to rules and regulations would be required in the long term to create a nation-wide solution.

Use Case 2: Repositioning Flight Traveling from KDAL to Downtown Dallas Within Class B Airspace

This use case proposes three route options for repositioning a vehicle (without passengers) from DAL airport to Dallas Downtown existing heliport 49T (see Figure 11). As can be seen in Figure 11, the routes in the use cases are named and used in the LOA. The actual names used in the LOA may differ, but for simplicity the routes are named here by colors as “Magenta Route,” Orange Route,” and “Blue Route.” Repositioning of vehicles may be necessary if the demand for the UAM operations is from a vertiport where the vehicles are not readily available (e.g., commuter traffic may require vehicles for flying from downtown to the suburbs).

This use case explores such a situation where a UAM vehicle needs to be repositioned to Dallas Downtown. Of the options, the Magenta to Blue Route continuing inside the UNICOM area is preferred since it requires the least amount of interaction with ATC. The other route options are the Green Route (crossing DAL midfield to runway 35E), which requires coordination with traffic using the runways, and the Orange Route. The Orange route, which is part of the existing helicopter route Tollway requires ATC coordination with conventional flights since Tollway is close to south departures from DAL. Thus, this use case will focus on the Magenta to Blue Route only shown as the Magenta route in Figure 11.



Maps Data: Google Earth 2019, Image Landsat/ Copernicus

Figure 11. Use Case 2, Repositioning aircraft from KDAL to Downtown Dallas, Vertiport 49T.

Procedural Steps for Use Case 2

The tasks by flight phase are predominantly the same as the previous use case; however, the takeoff requires a clearance from the DAL Tower controller since the origin is within Class B surface area. Upon entering the UNICOM area, as per the LOA, the PIC would switch to the UNICOM frequency.

Pre-flight and Pre-Departure

The pre-flight and pre-departure phases are the same as in Use Case 1, except that because this flight is for repositioning of the vehicle and passengers are not being transported. Also, a Class B clearance is required from ATC prior to takeoff in Class B airspace.

Departure Phase

The PIC switches to CTAF to inform the vertiport manager of the intention to taxi to the assigned pad. The vertiport manager acknowledges the PIC and informs that the pad is available and that there are no known inbound aircraft. The PIC acknowledges and begins taxi to the pad.

The PIC contacts DAL Tower for a departure clearance. In this use case, it is assumed that the requested route is the Magenta route that has least interaction with DAL departures. DAL Tower provides Class B clearance along with the departure advisory “Departure from (UAM ramp) will be at your own risk, use caution.” DAL Tower may issue additional instructions as necessary with the departure advisory. The PIC reads back the clearance to DAL Tower then, as in the previous use cases, lifts to a 5 ft hover for system checks. After system checks are complete, the pilot transitions the aircraft to forward flight and activates the autopilot after transition.

En Route Phase

During the en route phase of flight, DAL Tower requests the PIC to identify themselves (IDENT), and the PIC identifies themselves for DAL Tower. DAL Tower radar identifies and verifies Mode C for the UAM flight. As in the previous use cases, the PIC monitors the locations of nearby aircraft by direct visual scan out the cockpit and an ADS-B In display, follows route conformance, and monitors the DAL Tower frequency. The aircraft flies the Magenta route that commences with the Lover's Lane departure, crosses Tollway, and intercepts the Central Expressway helicopter route. ATC provides typical services within Class B (e.g., separation services and traffic calls, as needed).

Approach and Arrival

If current day procedures were followed, PIC would obtain a landing advisory and be asked to switch frequencies to the Downtown Dallas UNICOM frequency. The landing advisory would read as follows: “Joby 303, landing at Downtown Dallas vertiport will be at your own risk. Use caution [if applicable], RADAR service terminated; frequency change approved.” The PIC reads back the advisory to DAL Tower and switches to the UNICOM frequency.

If an LOA is in use, the PIC would switch to the Dallas Downtown UNICOM frequency at the coordination fix RUBBLE without any interaction with ATC. The PIC would use this frequency to contact the vertiport manager for their landing and parking information. The UNICOM frequency is also beneficial in that it allows for situational awareness of other pilots also flying in the UNICOM area. The vertiport manager informs the PIC that the landing pad and parking pads are available and open for their use. The PIC performs the landing checklist and begins deceleration from cruise flight speed. The PIC reports turning final to the arrival pad on the UNICOM frequency, and the aircraft transitions to vertical flight and lands. The vertiport manager confirms the parking pad to the pilot. The post flight phase for Use Case 2 is the same as in Use Case 0.

The use case development sessions revealed that it could be difficult for a controller to keep pace even with the small number of UAM operations being proposed in the near term in Class Bravo since they have a relatively low number of helicopter aircraft in the current day environment. UAM flights, like helicopter flights, will separate from each other, but the controller will be responsible for separation between the UAM flights and conventional traffic in Class B.

Conclusions for Use Case 2

The main conclusion for Use Case 2 revolved around concerns about scalability, due to the potential for increased controller workload required to separate UAM flights from arrivals and departures close to the airport. The route design as described earlier in the approach section can support separation between UAM and conventional traffic to keep ATC workload in check. Other possible solutions might be to add a helicopter position to the DAL Tower, create digitally coded routes and, in the long term, introduce new automation and roles such as the PSU. The PSU is a central data repository and could relieve ATC of some functions [5, 6].

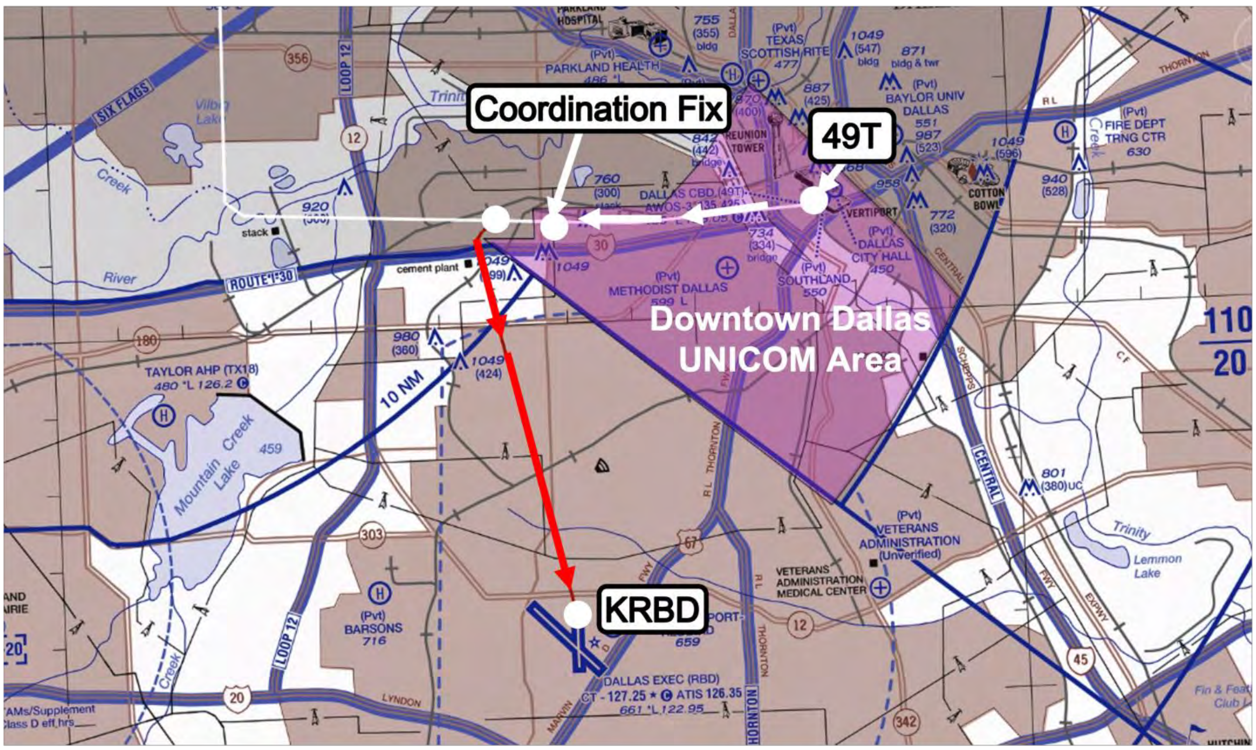
UAM aircraft will require beacon codes when in controlled airspace. A separate beacon code could be assigned to each UAM flight or UAM operator by the controller, adding to their workload. Another possibility is to assign the beacon code to the UAM operator via LOA. The issue of possible radar screen clutter due to the use of beacon codes was discussed and noted as a research question.

Use Case 3: Aircraft Redirected During a Flight from Class B Airspace to Land in Class B Airspace

Use Case 3 is a flight that departs from Downtown Dallas and is destined for DFW airport. It requests a diversion to Dallas Executive Airport (RBD) due to a sensor indicating a potential nacelle actuator fault (see Figure 12 for the Use Case 3 route including the diversion in red). Aircraft sensors detect a potential fault in the actuator that tilts the nacelle housing for one of the rotors and electric motors, which may render it incapable of performing its intended function.

This condition does not constitute an emergency, but it does require diversion to an airfield where conventional landing is possible since vertical mode is not desirable. This prompts the PIC on board to request to land at a close by Class D airport Redbird (RBD), which is an airfield that can accommodate a conventional landing without disrupting the sequence of arriving aircraft at DFW.

Note that since this use case requires the diversion to RBD, it does not include the completion of the flight to DFW, which is covered in the next Use Case 4a. One of the procedures discussed as a proposed mitigation for Use Case 4a is to have the PIC request a Class B clearance from the DAL helicopter position prior to take-off while still inside the UNICOM Area (see next use case).



Maps Data: Google Earth 2019, Image Landsat/ Copernicus

Figure 12. Use Case 3, KDAL rerouted to KRBD.

Procedural Steps for Use Case 3

Pre-flight, Pre-departure, and Departure Phases

Pre-flight, pre-departure and departure procedures are discussed in Use Case 4A. The pre-flight phase is the same as Use Case 1 except a pre-clearance is provided to the flight while it is still on ground (see Use Case 4a).

En Route (Diversion Procedures)

The PIC performs routine duties during flight (e.g., monitoring navigation, see and avoid, responding to ATC instructions/calls, etc.). ATC provides typical services within Class B (e.g., separation and traffic calls, as needed). The initial en route procedures at the coordination point are described in Use Case 4a.

Diversion

While transitioning to wing-borne flight, the PIC receives an indication on the flight deck display that the aircraft is experiencing a nacelle actuator sensor fault. Company procedures require that the PIC conducts a wing-borne landing under these circumstances. The PIC decides the best course of action is to avoid tilting the nacelle and desires to make a wing-borne landing instead of a vertical one. The PIC advises DAL Tower of nacelle actuator sensor fault and their decision to proceed to RBD at a reduced speed. DAL Tower acknowledges the request to divert and executes all required coordination with RBD and other entities. Time permitting, the PIC advises the flight follower of the diversion. DAL Tower hands off the flight to RBD Tower.

The flight follower monitors the aircraft deviating from its planned route to be consistent with an existing contingency plan. The flight follower is also in touch with all fleet aircraft so they can be alerted to aircraft not following the nominal operation plan. The flight follower would also likely dispatch an operations and maintenance response team, in addition to arranging ground transportation.

Approach and Arrival

The PIC contacts RBD Tower and requests Runway 17. RBD Tower instructs the flight to proceed inbound to Runway 17 and issues a landing clearance. RBD will ensure that all emergency notifications, if needed, are made. The PIC acknowledges the landing clearance and performs a wing-borne landing. RBD Tower instructs the PIC to contact the ground controller, who then provides a clearance to taxi. The PIC receives the clearance and taxis to a designated parking spot.

The PIC completes the post-flight check list, and the flight follower schedules maintenance to repair the faulty sensor. As described above, the PIC and flight follower coordinate on the dispatch of the operations and maintenance team as described above. The passengers are transported to DFW, their destination, by ground transportation.

Conclusions for Use Case 3

Use Case 3 focuses on a diversion rather than an emergency. The main take away from Use Case 3 development was that there is a need for thorough contingency planning to manage a diversion to an alternate vertiport. A deeper dive into this type of scenario would focus on exploring the roles and responsibilities of the flight follower, PIC, controller, and automation in a human-in-the-loop simulation.

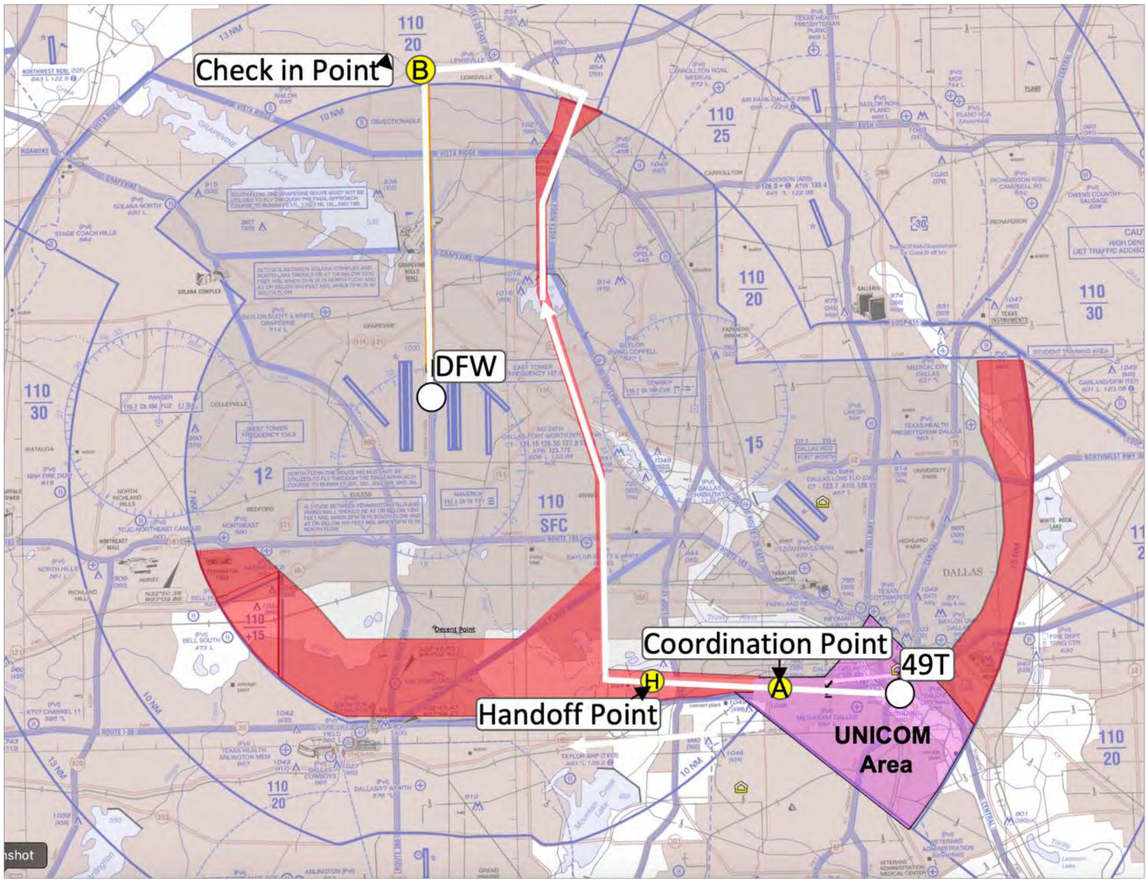
Use Cases 4a and 4b

Use Cases 4a and 4b investigate UAM flight that are destined for DFW airport. These flights utilize a current day helicopter route, commonly referred to as Spine Road, which is a 1,400 ft wide road between the East and West complexes of DFW airport. The Spine Road has lateral separation greater than 2,500 ft from the centerline of the inner runways (17R and 18L). It has unique challenges since there are crossover departures (from one complex to the other) that fly over the Spine Road. These use cases explore UAM flights going in the same direction as the flow of the legacy traffic as well as going in the opposite flow. They also investigate two different locations for vertiports at DFW airport.

Use Case 4a: Flight from Downtown Dallas Approaching DFW from the North

This flight is planned from Dallas Downtown to DFW airport, arriving at DFW from the north in the same direction as the DFW arrival flow (see Figure 13) and approaching to land at the

Corporate Aviation Ramp (Figure 14). The flight is handed off to the DFW Tower by DAL Tower at the handoff point shown in Figure 13. The aircraft, which is flying at 1,600 ft MSL (1,000 ft AGL), checks in with DFW Tower again at Check-in Point B as it turns towards the Spine Road prior to descending on its approach path. An LOA is proposed that may define procedures for the flight, such as approval for the route and phraseology for departure and landing instructions. The en route procedures may also be defined in the LOA, where the phraseology for a landing advisory to land at the Corporate Aviation Ramp is included.



Maps Data: Google Earth 2019, Image Landsat/ Copernicus

Figure 13. Use Case 4a, Downtown Dallas (49T) approaching DFW from the North.

Maps Data: Google Earth 2019, Image Landsat/ Copernicus

Figure 14. DFW terminals and corporate ramp location.

Procedural Steps for Use Case 4a

Pre-Flight

Procedures are the same as outlined in Use Case 0.

Pre-departure

During pre-departure, the UAM flight follower creates and transmits an operation plan to the PIC's EFB. The current day procedures require the PIC to request a Class B clearance after the flight has taken-off and reached a coordination point. However, the current day procedure is not desirable for eVTOLs that may need to hover while waiting for a Class B clearance from DAL Tower due to energy concerns. With current day procedures, the DAL Tower would have to check with DFW Tower if they will accept the UAM flight before clearing it or handing it off to DFW on flight-by-flight basis.

A proposed LOA allows the PIC to request a Class B clearance prior to departure for the route to DFW airport shown as the White Route in Figure 13. The LOA defines a coordination point (e.g., A) inside the UNICOM area where the departing flight will need to arrive at that coordination point within a pre-defined time for the clearance to remain valid. This pre-departure Class B clearance provided by the DAL Tower position would be given after assurance from DFW Tower personnel that the route to DFW is open. DAL Tower provides the clearance to the PIC and requests a check in at Coordination Fix A. These steps would also be outlined in the LOA as part of the coded-route approval. The taxi procedures followed by the PIC are the same outlined in Use Case 0.

Departure

Prior to takeoff, the PIC announces their intent to depart on the Downtown Dallas UNICOM frequency. The aircraft then takes off from the TLOF and must meet the requirement of either taking off or reaching Coordination Point A at a specific time as outlined in the LOA. ATC would potentially need a timeline display to show that the flight actually took off within the specified time or reached the coordination point.

Enroute

While enroute, and prior to Coordination Point A, the PIC switches from the UNICOM area frequency to the DAL Tower frequency and checks in with the DAL tower controller. DAL Tower requests the PIC to IDENT and the PIC complies. This allows the controller to identify the flight, verify Mode C, and locate the flight on their radar display. The check-in for that flight is then complete.

DAL makes a handoff to DFW Tower (Figure 13, Handoff Point H) and instructs the PIC to switch to the DFW Tower frequency at the appropriate location. The PIC switches to the DFW Local East Tower frequency. Under current day procedures, the flight would leave Class B for a short period of time and check-in again at with the DFW Tower at Coordination Point B to request entry to Class B.

An LOA would allow the UAM flight to leave Class B airspace and re-enter without the need for a new clearance. This check-in acts a reminder to the DFW local controller that the flight is on the Spine Road (the road between the East and West DFW complexes) and is approaching the Corporate Aviation Ramp. The UAM flight flies over and along the Spine Road (see Figure 14). This road is separated by more than 2,500 ft laterally from the approaches descending into the 17C and 17L, and so does not require wake turbulence callouts by ATC until the flight turns into its approach phase. However, the Class B separation requirement of 1.5 mi lateral or 500 ft vertical will be violated by the UAM aircraft on Spine Road as they descend, which may be mitigated by delegating the separation responsibility to the pilots.

Approach and Arrival

As the aircraft turns final down the Spine Road, the pilot contacts the tower at Check-in Point B (Figure 13) per the LOA. In the current day environment, the DFW Tower would provide a landing advisory with the phraseology “landing at your own risk, apply caution” and would ask the flight to switch frequency to the Corporate Aviation Ramp controller to every UAM flight about half a mile from the Corporate Aviation Ramp. The proposed LOA would include the landing advisory that the DFW local east controller would have issued for landing at the Corporate Aviation Ramp. At a pre-determined point on the Spine Road about half a mile from the ramp, as outlined in the LOA, the PIC would switch to the Corporate Aviation Ramp frequency without any interaction with ATC. The ramp operator (similar to a vertiport manager) provides a landing location and parking spot to the PIC. The rest of the turnaround procedures are the same as those discussed in Use Case 0.

Conclusions for Use Case 4a

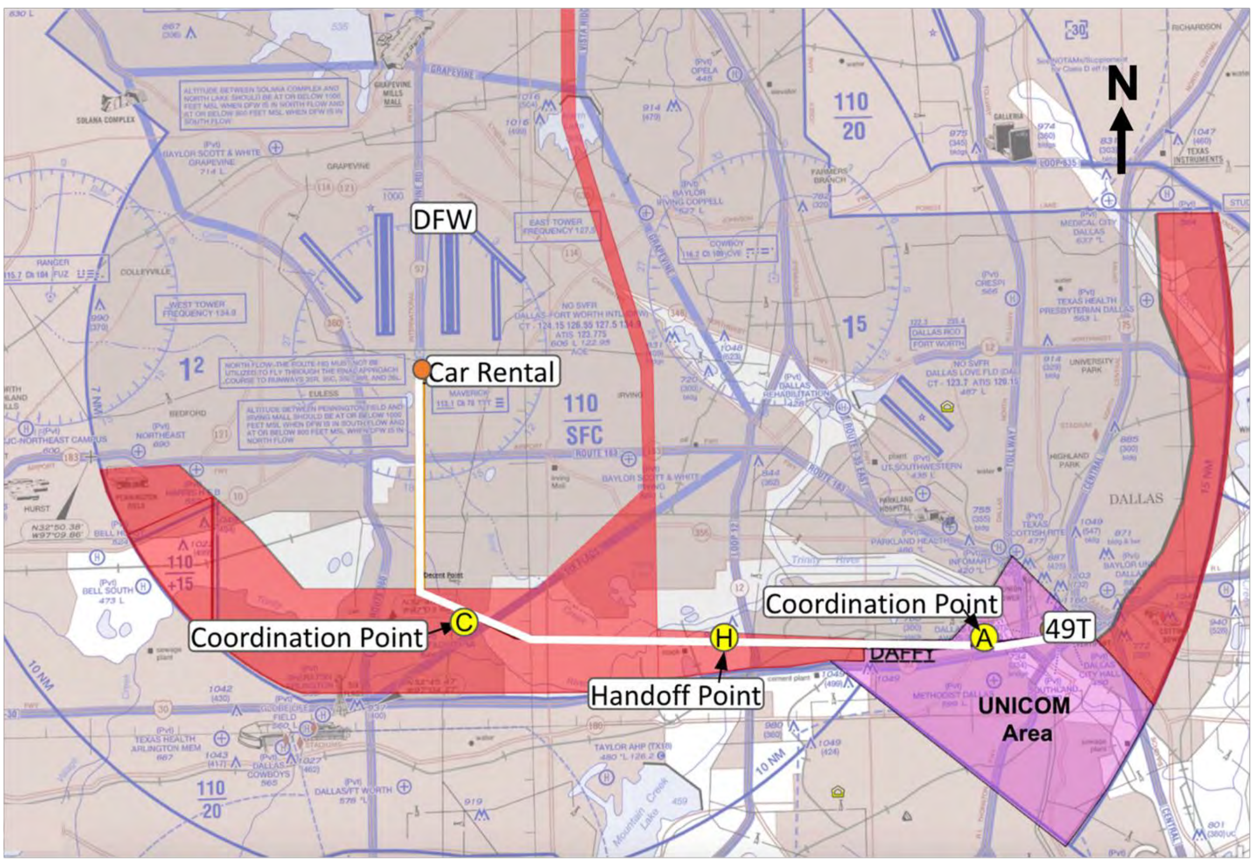
The main take away from Use Case 4a is that procedural changes may be needed to get a pre-clearance from the DAL Tower. This pre-clearance will require coordination with DFW Tower to ensure that the route is open and available for UAM flights so that this coordination is not required for every flight. DFW Tower will have to examine their workload with traditional flights prior to making the route ‘open and available.’ Also, procedures for switching the flight to the Corporate Aviation Ramp controller’s frequency by the DFW Tower controller need further investigation. These procedures, if outlined in an LOA, could potentially support future scalability.

Use Case 4b: Flight from Dallas Downtown Approaching DFW From the South

In this use case, the UAM flight approaches DFW from the south, which is in the opposite direction of the DFW arrival flow. The flight is planned to arrive at the DFW Car Rental Facility, which is the proposed vertiport location (see Figure 15). The aircraft flies at approximately 900 ft MSL (300 ft AGL) over the Spine Road as it approaches the Car Rental Facility. An LOA provides procedures for the flight that may include the approved route, pre-assigned beacon codes, and phraseology for departure and landing instructions.

Prior to departure, the PIC receives a Class B clearance from the DAL Tower helicopter position to reach Coordination Point A (Figure 15) within a predefined time. This pre-departure Class B clearance provided by the DAL Tower position would be transmitted after assurance that the route to DFW (White Route in Figure 15) is open and operational.

The take-off and en route procedures are similar to Use Case 4a except that the DFW local east controller provides the PIC with an advisory to land at the DFW Car Rental Facility as specified in the LOA and expects them to switch to the vertiport frequency for that facility (shown in Figure 15).



Maps Data: Google Earth 2019, Image Landsat/ Copernicus

Figure 15. Use Case 4b, from Downtown Dallas (49T) approaching DFW from the south.

Procedural Steps for Use Case 4b

The pre-flight and pre-departure phases are identical as in Use Case 4a. Prior to departure, the steps are identical to Use Case 4a.

While en route, the flight follower monitors the flight and the PIC continues to aviate, navigate, and communicate. The rest of the procedures are identical to Use Case 4a with the exception that the flight is moving in the direction opposite to the flow of legacy traffic. The current day procedures require that ATC provides traffic advisories to the UAM aircraft. However, the LOA can be written in a way that the advisories are included when the flight checks-in at Coordination Point C, where the UAM flight will be asked to switch to the Car Rental Facility's frequency.

The approach and arrival procedures and the post-flight procedures are the same.

Conclusions for Use Cases 4a and 4b

One of the conclusions that came from the development of Use Cases 4a and 4b was the challenge that radar displays would not be adequate to assist tower controllers to visually locate and identify flights that are flying at low altitudes (approximately 900 ft MSL/300 ft AGL) on the Spine Road.

In general, there are several challenges for the UAM flights approaching DFW on the Spine Road in both directions (north and south). They may interact with (legacy) departure traffic that crosses over the Spine Road between the east and west runways within 3 nm of the runway thresholds for efficiency or weather. The next section presents the detailed analysis of this crossover traffic over Spine Road.

The wake advisory requirement is mostly met due to the lateral separation between Spine Road and arrivals being greater than 2,500 ft except when the UAM flight is landing on the Corporate Aviation Ramp. Under VFR conditions, UAM flights on Spine Road will require visual separation between the UAM flight and legacy traffic approaching the runways. The current day rules require that in Class Bravo, VFR aircraft must be separated from aircraft that weight more than 19,000 lb and turbo jets by 1.5 mi lateral or 500 ft vertical, which is not available due to the placement and geometry of Spine Road and runways. To achieve this, visual separation may be applied by ATC or delegated to the pilot. ATC can provide visual separation only when wake turbulence advisories are not required, as is the case on Spine Road. To ensure that ATC can accomplish this, there will be a requirement for the aircraft to be tuned to the tower frequency. Delegating visual separation responsibility to the pilot can help reduce ATC workload but will add to the pilot's tasks and potentially their workload.

The placement of Spine Road between the East and West complex is such that there is greater than 2,500 ft lateral separation from the arrivals into the outer runways (17L and 18R), so ATC does not need to provide wake advisories to the legacy or UAM flights except when they are landing at the vertiports located at the Car Rental facility or Corporate Aviation ramp. Wake turbulence advisories provided by ATC as per the ATC handbook may not resolve the issue of wake from heavy and large aircraft.

The local controller managing both runway operations and UAM traffic may experience high workload and may require additional positions to support them during those conditions. Providing separation and the associated communications could create a significant workload for the controller, whose primary responsibility is to manage the conventional traffic. The limits on the scalability of this approach should be examined through simulation, analysis, and testing. The section on "Analyses of Spine Road Route" describes analyses to show the separation between the UAM flights taking this south and north route from Downtown Dallas to DFW and the conventional traffic in the area.

Analyses of Crossover Traffic Over Spine Road

NASA and Joby Aviation collectively evaluated some of the challenges of using the DFW Spine Road Route (as in Use Cases 4a and 4b). Since the route is between two major DFW complexes (East and West), there were concerns about whether UAM traffic would have the necessary separation when conventional flights cross between the runways and over the Spine Road planned for UAM operations.

The Massachusetts Institute of Technology [15] provided historical data on flights in the DFW airspace. The data set included Airport Surface Detection Equipment, Model X (ASDE-X) radar trajectory data for 100 days from April 2015 to March 2016. This was used to assess potential interactions between conventional flights and UAM aircraft along the Spine Road route. Approximately 135,000 departures were evaluated in North Flow (44,534 flights) and South Flow (90,392 flights) airport configurations. Departure trajectories were identified that crossed over the Spine Road within 3 nm of the runway thresholds.

Aircraft at DFW may cross over between runways 17L and 18R for several reasons. The most common one is to ensure predictability such as situations when the ATC changes runways due to operational necessity (e.g., caused by weather or to reduce taxi times). Other reasons for departure crossovers are a safety-related breakout on arrival or an unplanned go-around but these occurrences are unusual.

The goal of the analysis was to detect low altitude crossovers that were less than 1,000 ft above the expected UAM aircraft maximum altitude of 900 ft MSL. Vertical separation of 1,000 ft between the traffic is required to avoid the need for wake turbulence advisories that would impact the controller's communication workload. The requirement for at least 500 ft vertical or 1.5 mi lateral in Class B would assure radar separation between the legacy flights and the UAM traffic. Figure 16 is a depiction of a crossover flight that does not meet the 1,000 ft vertical separation requirement. In that situation the controller would be required to provide the wake turbulence advisory. The wake of the much larger crossover traffic could be a safety concern for the UAM traffic.

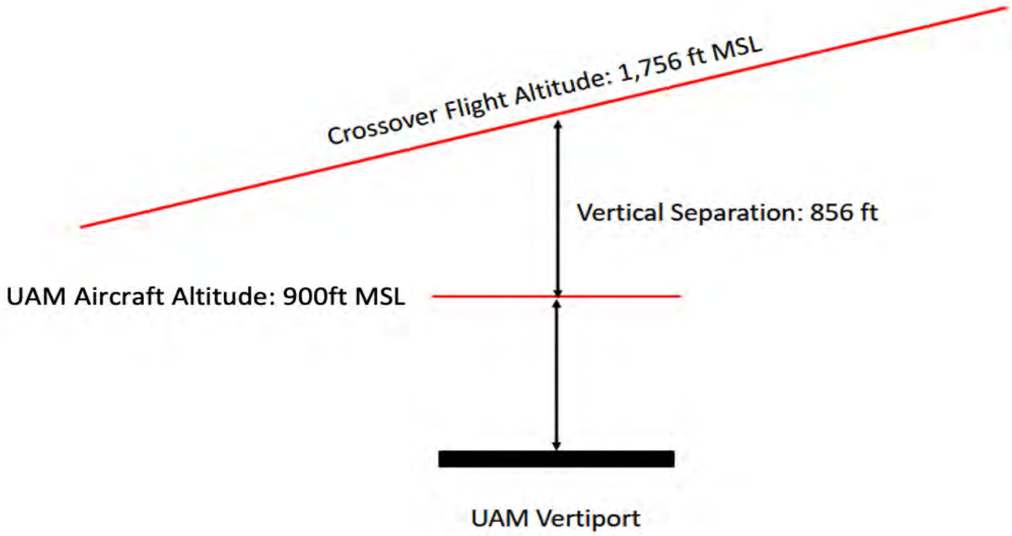


Figure 16. Notional example of a low departure crossover.

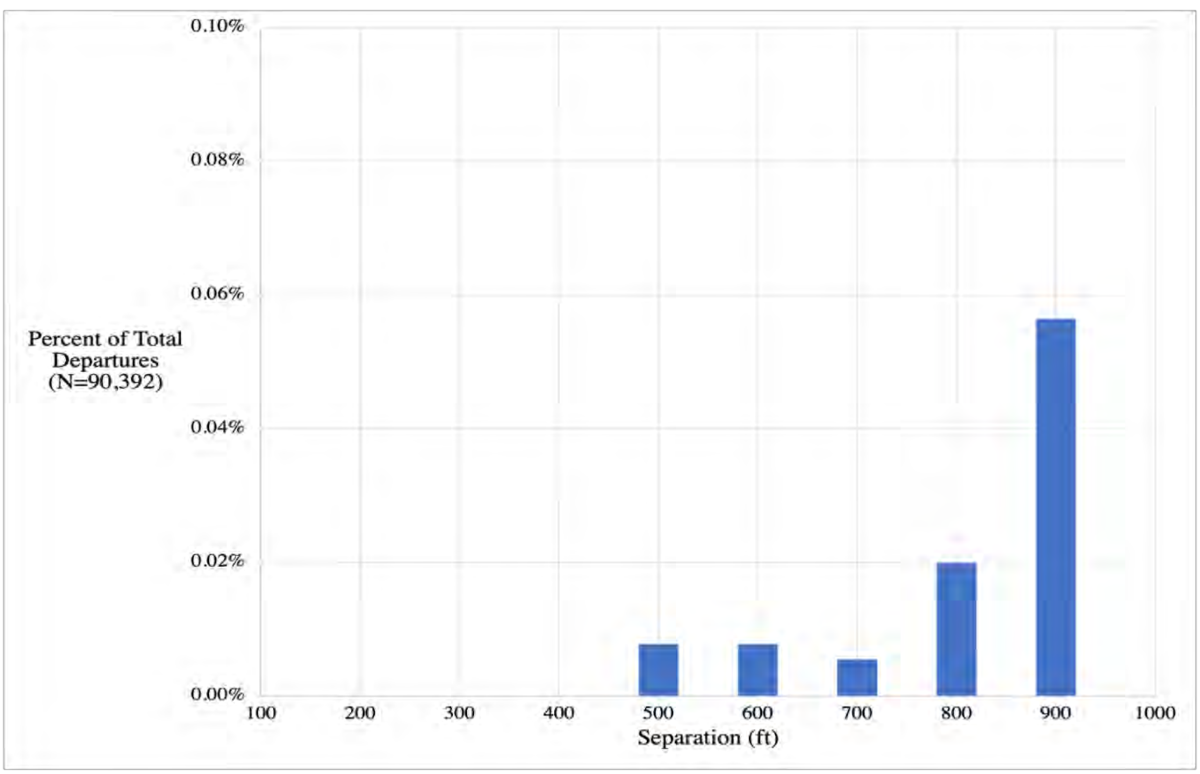
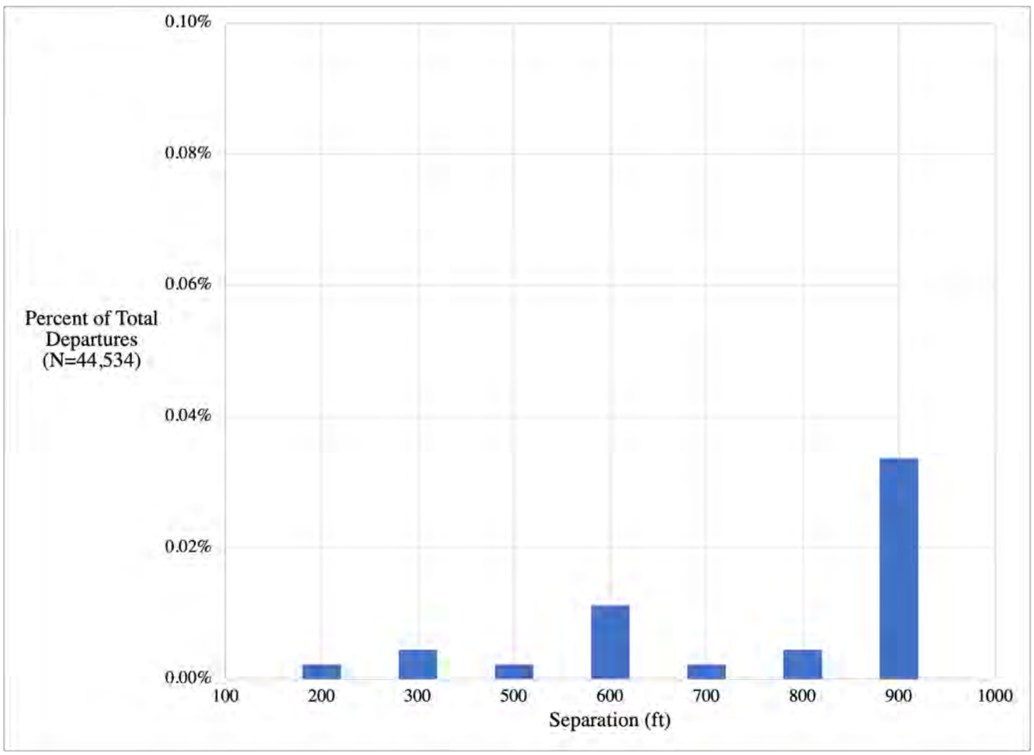


Figure 17. Percentage of low crossover (below 1,000 ft) traffic compared to total departures in South Flow (N=90,392).

Figure 17 and Figure 18 show the distribution of vertical separation between the expected UAM altitude of 900 ft MSL and the low crossing departures (legacy traffic) in South and North Flows respectively. There are a relatively small number of low crossovers and most of them are just below the required 1,000 ft. In South Flow, there were a total of 820 crossovers of which 88 were low departure crossovers (less than 1,000 ft above the UAM aircraft at 900 ft MSL). For North Flow (Figure 18), there were a total of 197 crossovers of which 27 were low crossovers.

These numbers are relatively low when compared to the total number of departures over the 100-day period, yet they will need to be addressed. If not addressed, the impacted aircraft will need a wake advisory provided by ATC, adding to their communication workload. A possible strategy to mitigate the problem is for ATC to permit the departure crossovers for legacy traffic only after the aircraft have reached 2,000 ft MSL during their climb out. This procedural change



would allow UAM traffic to operate on Spine Road without additional wake advisories provided to them or to the legacy traffic. However, wake separation procedures may still be required, for example, if there is a heavy aircraft crossing over, it will require that a small UAM be separated by 2 min, this has implications for controller workload and needs to be further investigated.

Figure 18. Percent of low crossover traffic compared to total departures in North Flow, (N = 44,534).

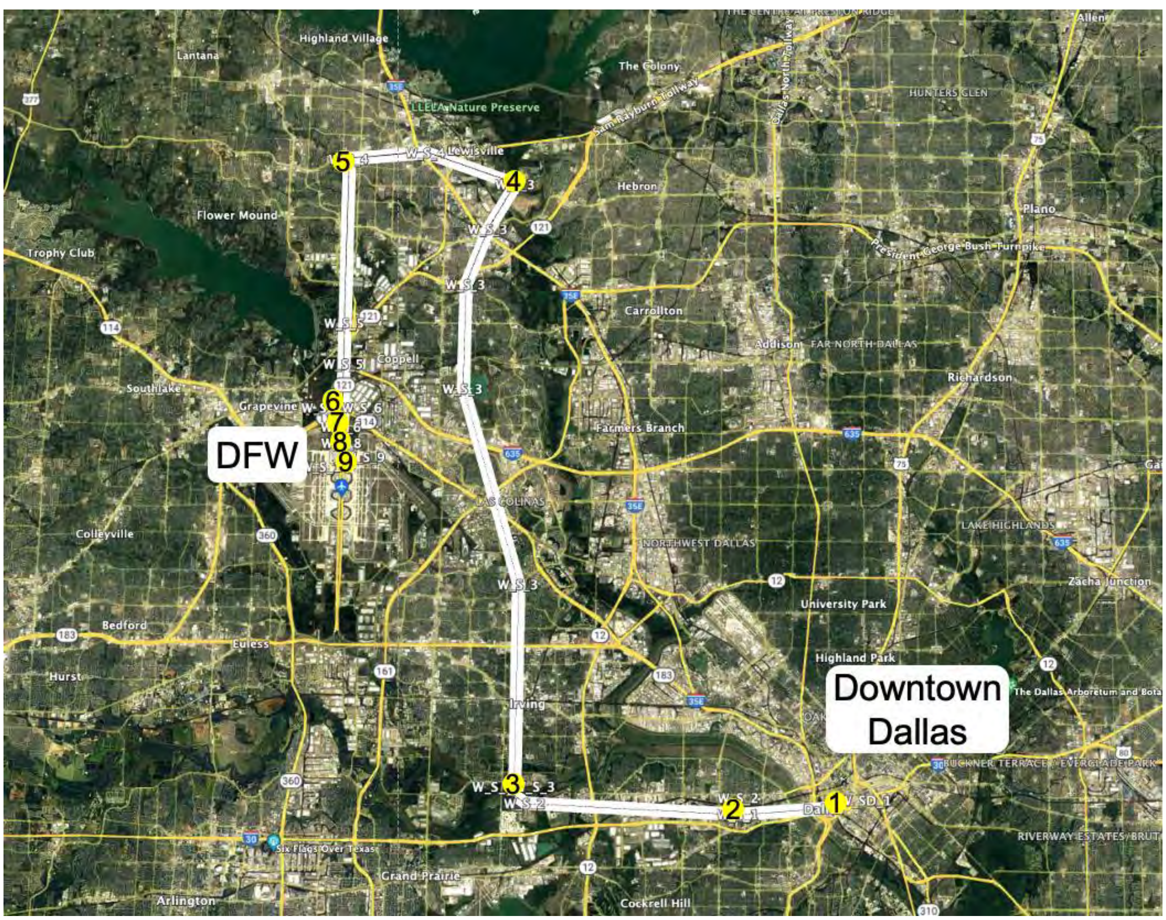
Analyses of Spine Road Route

Analyses were conducted to determine if the UAM routes employed in the use cases were procedurally separated from conventional traffic. Six days of flight track data were used. From January 1-3, 2018 the traffic was in North Flow and from January 4-6, 2018 it was in South Flow. Two criteria, separation and wake advisory, were used to assess separation of the legacy traffic from the Use Case 4a and 4b routes. Only the track data from conventional flights below 3,000 ft MSL were included in the analysis. These track data were compared to a route with the altitude of 1,000 ft AGL. This data is different from the data used for cross over analysis in the previous section.

The two criteria used were the wake advisory requirement and the Class B aircraft separation requirements for aircraft weighing greater than 19,000 lb. Wake advisory criteria requires that ATC provides an advisory to the aircraft if they are separated by less than 2,500 ft lateral or 1,000 ft vertical. The separation criteria require aircraft to have a minimum separation of 1.5 mi lateral or 500 ft vertical between aircraft that weigh greater than 19,000 lb.

The routes for Use Cases 4a (see Figure 19) and 4b (see Figure 21), were broken into segments and examined at 1,600 ft MSL (1,000 ft AGL) using the two separation criteria with respect to DFW arrivals and departures in North and South flows. If either the lateral or vertical separation requirements for the two criteria were not met for the UAM flight and legacy flight for a percentage greater than 5%, then those flights would require greater tactical handling by ATC.

For the purpose of this evaluation, the handling of greater than 5% of such encounters by ATC was deemed as unacceptable based on SME discussions. However, the precise percentage of flights that would be acceptable is yet to be determined. Encounters greater than 5% mean that the design of the route did not completely resolve the need for ATC interaction. The percentages described in Table 1 and 2 are the number of times that separation criteria were not met as compared to the total number of arrivals or departures for that flow. The percentages above the 5% threshold are highlighted in Tables 1 and 2.

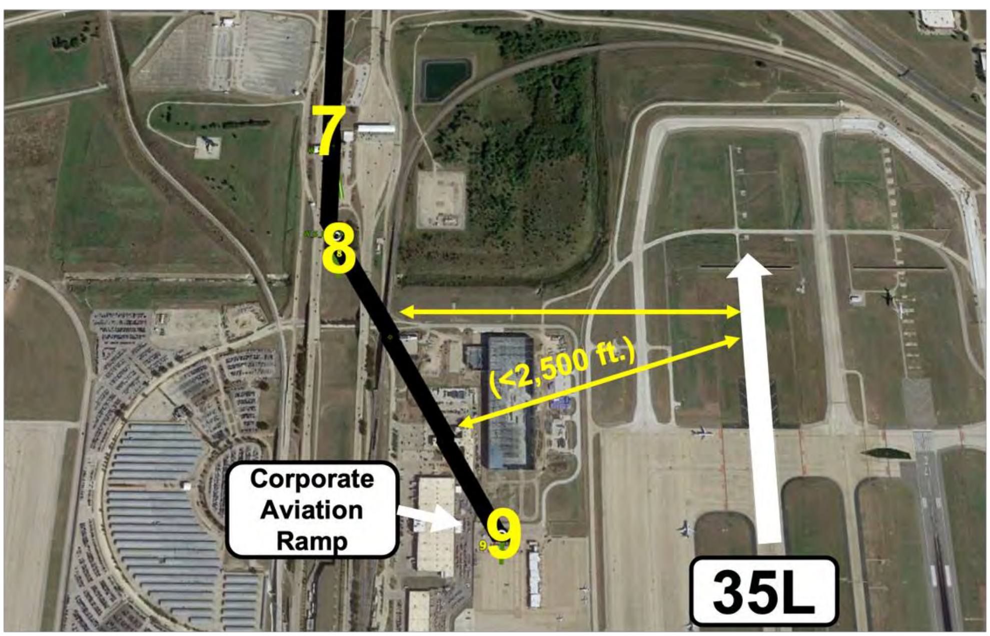


Maps Data: Google Earth 2019, Image Landsat/ Copernicus

Figure 19. Use Case 4a segmented route (bird's eye view)

Table 1. Percentage of DFW arrivals and departures that did not meet wake advisory criteria for the route in Use Case 4a.

Use Case 4a. Wake Advisory Criteria (2,500 ft lateral or 1,000 ft vertical)				
	DFW Arrivals		DFW Departures	
Segment #	North Flow (N=2,661)	South Flow (N=2,594)	North Flow (N=2,624)	South Flow (N=2,586)
1	0%	0%	0%	0%
2	<1%	0%	0%	0%
3	<1%	<1%	<1%	0%
4	0%	3%	0%	0%
5	0%	1%	<1%	0%
6	0%	0%	<1%	0%
7	0%	0%	<1%	0%
8	0%	0%	<1%	0%
9	<1%	0%	**42%**	0%



Maps Data: Google Earth 2019, Image Landsat/ Copernicus

Figure 20. Use Case 4a segmented route with focused view of a North departure from DFW.

Table 1 depicts the results of the analyses for the Use Case 4a route. When using wake advisory criteria for DFW arrivals and departures and comparing it to Use Case 4a, few or no conflicts were observed with traditional traffic, except for Segment 9 (Figure 20) for DFW departures in North Flow. This is expected since most of the route (Spine Road Segments 5 through 8) has 2,500 ft lateral separation from the centerlines of the inner runways. This ensures that the wake advisory requirement is mostly met in South Flow. Forty-two percent of departures in North Flow did not meet the wake advisory requirement for Segment 9 that goes toward the Corporate Aviation Ramp, which is less than 2,500 ft from the runway 35L centerline as shown in Figure 20.

The geometry of the departure procedures for 35L are such that an altitude separation of 1,000 ft will not be met with UAM aircraft on Segment 9 in North Flow because they are just beginning to roll and climb (Figure 20). This would require that ATC provide the wake advisory to all the aircraft affected. It does not prohibit UAM operations but makes scalability challenging due to the required ATC communications. Another way to mitigate this issue would be to place the vertiports at a location that have the required wake advisory separation.

The 3% of the flights that do not meet the criteria for Segment 4 that is outside Class B is due to legacy traffic crossing the segment lower than expected under visual conditions. This can be mitigated by having the legacy flights cross Segment 4 at or above a specific altitude.

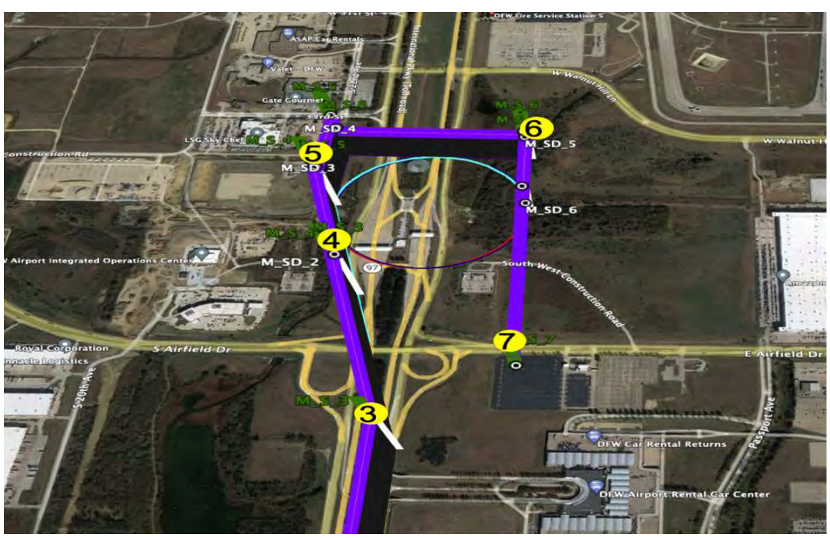
Table 2. Percentage of DFW arrivals and departures that did not meet separation criteria for route in Use Case 4a.

Use Case 4a. Class B Separation Criteria (1.5 mi or 500 ft. vertical)				
	DFW Arrivals		DFW Departures	
Segment #	North Flow (N=2,661)	South Flow (N=2,594)	North Flow (N=2,624)	South Flow (N=2,586)
1	0%	0%	0	0%
2	1%	11%	0	0%
3	1%	2%	1%	<1%
4	0%	**87%**	0	0%
5	1%	**87%**	**98%**	<1%
6	1%	**87%**	**98%**	<1%
7	1%	**87%**	**99%**	3%
8	1%	**87%**	**98%**	6%
9	1%	**98%**	**98%**	**43%**

Table 2 shows that the Class Bravo separation requirement 1.5 mi lateral or 500 ft vertical in Class B was not met for DFW arrivals in Segments 4 to 9 in South Flow or for DFW departures in Segments 5 to 9 in North Flow. For the most part, these occurred on the Spine Road close to the airport where 1.5 mi lateral separation is not available due to the geometry and distance between the Spine Road and the departing conventional traffic in North flow. Vertical separation of 500 ft is not possible until the departures climb above 500 ft AGL in North flow. Additionally, the Class Bravo separation criteria was not met for DFW departures in South Flow for Segment 9, which is the Corporate Aviation Ramp, for 43% of the flights. This result is likely due to departures on runway 17R that do not have 500 ft vertical separation as soon as they start their takeoff roll.

Maps Data: Google Earth 2019, Image Landsat/ Copernicus

Figure 21. Use Case 4b segmented route.



Maps Data: Google Earth 2019, Image Landsat/ Copernicus

Figure 22. Use Case 4b segmented route focused view of the approach into DFW.

For the Use Case 4b route (see Figure 21), it was found that there were few or no conflicts with DFW arrivals and departures for wake advisory criteria (See Table 3). Additionally, looking at departures in South Flow, 22% did not meet wake advisory requirements for Segment 6, and

14% of the departures did not meet wake advisory criteria requirements for Segment 7. Segments 6 and 7 (see Figure 22) are less than 2,500 ft lateral of the centerline of runway 17R so this result is likely due to departures that did not achieve 1,000 ft vertical separation as they departed. Finally, looking at the North Flow arrivals, Segment 2 had 7% of arrivals that did not meet wake advisory criteria. This may be caused by the arrivals on the runway 35L coming in from the Southeast and landing to the Northwest, resulting in a loss of the 1,000 ft vertical separation. These results require further analyses to be fully understood.

Table 3. Percentage of DFW arrivals and departures that did not meet wake advisory criteria for route in Use Case 4b.

Use Case 4b Wake Advisory Criteria (2,500 ft lateral or 1,000 ft vertical)				
	DFW Arrivals		DFW Departures	
Segment #	North Flow (N=2,661)	South Flow (N=2,594)	North Flow (N=2,624)	South Flow (N=2,586)
1	0%	0%	0%	0%
2	**7%**	0%	0%	0%
3	0%	0%	0%	2%
4	0%	0%	0%	4%
5	0%	0%	0%	3%
6	1%	0%	0%	**22%**
7	1%	0%	0%	**14%**

Table 4. Percentage of DFW arrivals and departures that did not meet separation criteria for route in Use Case 4b.

Use Case 4b Class B Separation Criteria (1.5 mi lateral or 500 ft. vertical)				
	DFW Arrivals		DFW Departures	
Segment #	North Flow (N=2,661)	South Flow (N=2,594)	North Flow (N=2,624)	South Flow (N=2,586)
1	0%	0%	0%	0
2	**90%**	0%	0%	0
3	**91%**	0%	0%	**98%**
4	**91%**	0%	0%	**98%**
5	**91%**	0%	<1%	**98%**
6	**99%**	0%	<1%	**98%**
7	**99%**	0%	<1%	**94%**

The Class Bravo separation criteria requirement was not met for DFW arrivals for Segments 2 to 7 in North Flow or for DFW departures for Segments 3 to 7 in South Flow (see Table 4). The Class Bravo separation criteria was not met for Use Case 4b when the UAM flights are on Spine Road and parts of Segment 2 because the radar separation requirement of 1.5 mi lateral or 500 ft vertical is not possible from the departing conventional traffic in South Flow and arriving DFW traffic in North Flow.

While further investigation is necessary to refine our understanding of these results, these analyses suggest that careful planning is needed to establish UAM routes and vertiport locations at DFW that will not increase ATC workload in the near term. The wake turbulence advisory requirement was mostly met for both Use Case 4a and 4b routes except with the segments close to the vertiports. However, radar separation requirement in Class B was not met for the most part suggesting that visual separation procedures will be necessary in the early implementation of UAM.

Findings

This section presents details on the challenges and potential solutions for initiating UAM operations at DFW. The analysis reveals that some near-term UAM operations are possible without any changes to rules, policies, or helicopter routes (where available). However, the placement of vertiports near active runways will pose challenges in near term implementation. There may be traffic management challenges to overcome as the number of operations increase compared to current day helicopter traffic in the area. However, flights in Class G and E airspace occur today without any need for controller communication and this will continue to be possible for UAM flights in the near term.

As UAM aircraft navigate the airport area, they may need to enter Class B controlled airspace, which requires an ATC clearance. For an aircraft to request entry, a predefined coordination point could be established prior to the Class B airspace boundary. The location of this fix must allow time for ATC to process the request. Provisions must be made to deal with aircraft delays, should they be required, while waiting to receive the Class B clearance. Since it would not be ideal for eVTOLs to hover to absorb delay due to high power consumption, a holding pattern outside Class B and associated procedures would be needed. Analyses are needed to determine the effect on upstream operations from possible delay bottlenecks such as at coordination points outside Class B airspace.

The UNICOM area proposed around Dallas Downtown has the potential of reducing workload for the DAL Tower controller so that flights could fly within UNICOM easily without Class B clearance (if repositioning) or traffic advisories, while separation is delegated to the pilot. UAM arrivals into and departures out of the UNICOM area may have transition or coordination points to allow the pilot flexibility while inside the UNICOM area. Improved pilot situation awareness would be achieved since the aircraft are likely to communicate using the same radio frequency. Further investigation is required to understand how UNICOM areas can be established. If they are created using an LOA, then operators, who are not signatories to the LOA could still fly in that airspace using existing ATC procedures and communications. Future research is necessary to understand the potential benefits and drawbacks of using a UNICOM area for UAM.

It was also found that procedures for granting access to controlled airspace prior to departure may be needed when flights are departing from UNICOM areas inside Class B airspace. For example, to facilitate entry into Class B airspace, DFW Tower could coordinate with DAL Tower to approve a UAM aircraft's intended route when headed for a vertiport at DFW. This would ensure that the receiving controller (DAL Tower) has assurance that the UAM flight would be cleared to DFW prior to take-off and have permission to enter Class B airspace instead of holding at a coordination point inside the UNICOM area. This would avoid traffic delays and excessive coordination between controllers managing different towers/airports.

An LOA is an existing tool that can be used locally to enable higher tempos of UAM operations with potentially acceptable controller workload in the near term. An LOA would be signed between UAM operators and FAA and other local facilities. For example, it could specify how a UAM aircraft is to request access to controlled airspace. An LOA could reduce the number of repetitive instructions controllers must give to UAM aircraft, thus minimizing impact on workload and voice frequency congestion. It can also define the exact routes with altitudes that the UAM aircraft would fly, thus providing strategic separation to these aircraft and reducing the burden of separation on ATC.

An LOA may also be used to pre-assign beacon codes, further reducing ATC workload. When in Class B airspace, UAM aircraft may be given beacon codes from a local bank of codes. There could be problems with radar display clutter due to the need to manage these codes. The FAA might instead use permanent beacon codes, or an LOA may be used to pre-assign beacon codes to the UAM operators. This relieves the controller from entering data into their terminal radar system to create a data block. However, if a permanent code is assigned to a UAM aircraft, it would not be available to ATC for pop-up temporary flight restrictions. The efficacy of pre-assigned or permanent codes will be a local judgment, heavily dependent on the mix of existing air traffic and operators.

As UAM aircraft enters some regions of Class B airspace, for example on the DFW Spine Road Route, the tower controller would need to provide visual separation under current day rules due to its distance from inner runways being less than the required 1.5 mi lateral separation requirement. To accomplish this, the aircraft must be visible from the tower, or this responsibility is delegated to the pilot. It may be difficult for ATC to visually acquire the UAM aircraft because of their relatively small size, the distance of the aircraft from the tower, and periodic poor visibility due to atmospheric conditions. This has implications for ATC workload as well as the type of UAM operations (VFR only) that can be conducted in the near term.

The wake advisory requirement between UAM aircraft flying on Spine Road, an existing helicopter and conventional traffic is mostly met because the lateral separation between Spine Road and the inner runways is greater than 2,500 ft. However, the UAM flights approaching the vertiports on Corporate Aviation Ramp or Car Rental facility do not have the required 2,500 ft lateral separation and vertical separation of 1,000 ft is also lost because the arrivals and departures are close to surface. This means that wake advisories will need to be provided when the UAM flights in their take-off and landing phase of flight as well as to legacy traffic in the vicinity.

There may be interactions between UAM aircraft flying between the parallel DFW runways using the Spine Road route and departing conventional flights. Departing aircraft routinely cross between the DFW 17L and 18R runways and over the proposed UAM area on the Spine Road. If separation requirements are not met, traffic and wake turbulence advisories must be provided by ATC to both conventional and UAM aircraft. To reduce the chance of UAM aircraft losing separation with this crossing traffic, it is proposed that ATC procedures be changed so that departure crossovers are not permitted to cross the runways until the aircraft reach 2,000 ft MSL. This would ensure adequate vertical separation between the UAM and conventional flights. In addition to controller workload considerations of issuing wake-turbulence advisories, the safety ramifications of UAM aircraft crossing below the wakes of large conventional aircraft with less than 1,000 ft vertical separation at low altitudes needs careful assessment. Wake separation requirements between heavy and small UAM may require ATC services.

Large conventional aircraft are equipped with the Traffic Alert and Collision Avoidance System (TCAS), which improves their ability to avoid collisions. There may be excess nuisance TCAS Resolution Advisories (RAs) and Traffic Alerts (TAs) caused by UAM aircraft flying between the DFW parallel runways. Research has shown that there are few RAs between aircraft going in the same direction [16]. Also, TCAS RAs are inhibited below 900 ft AGL and TAs are inhibited below 500 ft AGL. However, some alerts may occur between UAM and conventional aircraft at altitudes above these minima. Further analysis should examine the optimal alerts for these low altitude operations and explore the degree to which additional nuisance advisories may arise from new UAM operations.

Other interactions between UAM and conventional aircraft flying departures and approaches may not be predictable (e.g., visual approaches to DAL). For example, arriving aircraft may use visual approach procedures with variable altitudes. Controllers will need to provide separation services. Using an Area Navigation (RNAV) approach rather than a visual approach for the conventional traffic might be a potential solution to the problem. There is limited airspace for UAM aircraft maneuvering and a concern for increasing controller workload to manage separation. As a result, eVTOLs may need to take indirect routes to avoid arrival and departure streams to allow for separation, go-arounds, missed approaches, and crossover traffic.

The use cases explored in this paper were mostly nominal operations with the exception of one that focused on the diversion of a UAM flight from a Class B to a Class D airport. Use cases that focused on repositioning of flights within the UNICOM area or flights from Dallas Downtown to DFW in the opposite direction would need further investigation. Contingency planning, identification of alternate landing sites, and related procedures also require further exploration. Contingency planning for UAM aircraft diversions, emergencies, and other off-nominal cases will also require detailed assessment.

An analysis of proposed UAM routes has also shown that there may be limitations on airspace usage under specific airport configurations and with certain arrival and departure procedures. Some of the initial UAM routes are situated such that ATC will be providing wake turbulence or separation services in some airport configurations more than others. RNAV arrival and departure routes will provide more predictability for conventional flights that fly close to UAM routes. An LOA could structure these UAM routes and reduce the need for coordination and communication with ATC.

In the near term, UAM aircraft will use see and avoid to maneuver around other aircraft as required under VFR. The pilot's see and avoid capability could be augmented by systems like the Automatic Dependent Surveillance-Broadcast (ADS-B In and Out), but as traffic density increases new types of automation that are assistive in nature may be needed to ensure tactical separation. Detect and avoid systems designed for unmanned aircraft systems may be adapted to provide advisories for onboard, piloted eVTOL flight decks, ensuring pilots have assistance in remaining well clear of other aircraft in addition to tactical collision avoidance. Aircraft separation responsibility may be designated by the location of their operation (whether on a particular route or within a corridor), the certification of the aircraft, or through an FAA policy, similar to the treatment of helicopters in Class B airspace today. Separation services are not provided between pairs of VFR helicopters but are provided between VFR helicopters and conventional traffic or IFR helicopters.

The findings that emerge from the development, exploration, and discussion of these use cases suggest that initial UAM operations could occur under today's airspace and procedures in a busy terminal area, such as DFW and DAL, but will encounter significant challenges when scaling up and some desirable flight paths are constrained by existing traffic. As UAM aircraft navigate in and out of Class B airspace and require separation, previous research [9,10] has found that this is likely to have an impact on controller workload. Applying methods such as an LOA might reduce controller communications and workload. Also, the UAM aircraft will be flying near established conventional traffic flows and will require careful management. Some discussions revealed that DFW does not experience much helicopter traffic and thus depending on implementation, the addition of UAM traffic is likely to result in increased workload to tower controllers.

The two major constraints and concerns emerging from this use case development are that UAM operations will initially encounter are controller workload and the ability to efficiently and safely interact with existing airport traffic. As traffic increases, LOAs, UNICOM areas, corridors, and reclassifying airspace could support UAM flights. However, policy and rule changes and dedicated airspace structures (e.g., corridors) are likely to be needed to enable longer-term scalability.

Summary and Next Steps

NASA developed a set of five UAM use cases or traffic scenarios at DFW that were informed by FAA, DFW airport SMEs and industry partners. The goal of the exercise was to elicit feedback on how UAM aircraft could operate using existing airspace structures, rules, and procedures. This report describes the use cases and the resulting discussions.

The methods and assumptions for creating the five use cases are reviewed and the scenarios are described in detail. Use Case 0 explores the least complex example of a UAM flight departing from Frisco (in Class G airspace) and arriving at Garland Heliport (T57) also located in Class G. Use Case 1 describes a flight departing from Frisco and arriving at a Downtown Dallas vertiport (49T) located in Class B airspace. It differs from Use Case 0 in that it requires a clearance into Class B airspace. An LOA is introduced as a means for pre-defining some procedures to reduce the need for ATC voice communications.

Use Case 2 describes the repositioning of an eVTOL from DAL to Downtown Dallas. This use case assumes no passengers are on board since it is repositioning an aircraft from the airport to the downtown area. There are three route options discussed with one route expected to be the primary since it would require the least amount of interaction with ATC.

Use Case 3 describes a flight that departs from Downtown DAL enroute to DFW in which the pilot requests a diversion due to a sensor fault. The pilot requests permission to land at a nearby Class D airport (RBD), which is an airfield that can accommodate a conventional landing without disrupting the sequence of flights planned into DFW. Use Cases 4a and 4b describe flights departing from Dallas Downtown and arriving at DFW using the Spine Road route located between the East and West complexes of DFW. The UAM departure follows a predefined path and requests entry into Class B airspace at a coordination point located on the boundary of the UNICOM. Two routes are defined that allow a north or south approach to two different landing areas between the runways.

Spine Road as a UAM route poses several challenges due to current day departure traffic that crosses between the runways. Operations on the Spine Road route may pose risks if conventional aircraft cross over between the runways or go around in the vicinity of the area of UAM operations. Analyses of this crossover traffic showed that a procedural change to the crossover departing traffic would help ensure vertical separation between the conventional departures and the UAM traffic and potentially mitigate controller's communication workload. However, wake separation between heavy aircraft crossing over and small UAM planned on the Spine Road still applies and has implications for ATC workload.

The use case development discussions held between NASA, FAA, local facilities, and Joby Aviation revealed several challenges that need to be addressed to enable early implementation of UAM. Aircraft would need to contact ATC to enter the Class B, C, or D airspace. A method for absorbing or avoiding delays is necessary if entry to Class B airspace is not immediately possible. Provisions for airborne hold may be required. LOAs could be written to dictate specific procedures for entry into Class B airspace to reduce controller workload. Another strategy to manage ATC workload is the creation of a UNICOM area within Class B airspace that would reduce the need for ATC communication for repositioning flights. Air traffic facilities could also develop their own routes to support local UAM operation. Procedures would need to be changed to provide better altitude separation between UAM and conventional aircraft flying visual approaches.

As might be expected, operating UAM aircraft in a busy airport area requires consideration of many factors. Some UAM routes may be too close to conventional traffic to maintain radar separation for aircraft and/or avoid the need for wake turbulence advisories. There may be TCAS RAs or TAs triggered by the UAM traffic flying below conventional traffic. Traditional aircraft flying visual approaches may not follow predictable flight paths, requiring application of less-efficient tactical separation services. Procedural changes could remove some of these issues, but further study is needed to create solutions in specific airspaces. An analysis of the interaction between UAM operations and conventional traffic in urban areas has been undertaken [14], but further research in this area is needed.

The use case development and analyses suggest that further research should focus on early operations with simple use cases and progress to more complex evaluations. Questions about how to clear UAM aircraft into controlled airspace can be investigated by creating specific procedures. These could then be tested in human-in-the-loop simulations. It may be necessary to evaluate and compare several options such as the location of coordination points and holding areas, physical placement of routes, the effectiveness of a UNICOM area, changes to existing approach and departure procedures, use of beacon codes, and the workload effects of creating and utilizing an LOA. These alternatives should be reviewed by ATC and UAM subject matter experts to ensure they are feasible prior to any simulation or field testing. UAM elements such as corridors and the PSU could be added to a simulation to further test improvements in performance and safety.

Separation of UAM aircraft from conventional flights emerged as an issue in the discussions because they would further burden the controller to provide separation services and is not scalable in the long term. UAM routes and airport operations will need to be designed to eliminate or minimize separation problems between legacy and UAM flights. It is possible that conflicts could be managed by requiring departing aircraft to cross over the runways at higher altitudes. Separation questions could be initially addressed in fast-time simulations that use different combinations of UAM routes and conventional traffic patterns. Other long-term solutions for scalability have been proposed by the FAA UAM ConOps such as new airspace structures like corridors, where the UAM operators, third party service providers (PSUs) and pilots are responsible for tactical separation between UAM aircraft. ATC services and voice would not be required for UAM operations inside the corridors. However, these novel ideas need research and development.

Further research on UAM operations in the DFW airspace should focus on investigating topics that emerged in the use case exercise. Both fast time and human-in-the-loop simulations are an effective method for exploring initial solutions to these questions before any field studies are conducted.

List of Acronyms

ADS = Addison Airport
AGL = Above Ground Level
ATC = Air Traffic Control
ATO = Air Traffic Organization in the FAA
ConOps = Concept of Operations
CTAF = Common Traffic Advisory Frequency
DAL = Dallas Love Field Airport
DFW = Dallas Fort Worth
eVTOL = Electric Vertical Takeoff & Landing
FAA = Federal Aviation Administration
IAP = Instrument Approach Procedures
LOA = Letter of Agreement

MSL = Mean Sea Level
NAS = National Airspace System
PSU = Provider of Services for UAM
RBD = Dallas Executive Airport or Redbird
SID = Standard Instrument Departure
SME = Subject Matter Expert
STAR = Standard Terminal Arrival
TCAS = Traffic Collision Alert and Avoidance System
TLOF = Touchdown and lift off area
UAM = Urban Air Mobility
UCAT = UAM Coordination Team
UML = UAM Maturity Level
UNICOM = Universal Communications Station
UTM = UAS Traffic Management
VFR = Visual Flight Rules

References

[1] Mueller, E., Kopardekar, P., and Goodrich, K., "Enabling Airspace Integration for High-Density On-Demand Mobility Operations," 17th AIAA Aviation Technology, Integration, and Operations Conference, Paper 2017-3086, June 2017.

[2] "Fast-Forwarding to a Future of On-Demand Urban Air Transportation," Uber Elevate Report, 2017, https://www.uber.com/elevate.pdf.

[3] Thipphavong, D., Apaza, R., Barmore, B., Battiste, V., Burian, B., Dao, Q., Feary, M., Go, S., Goodrich, K., Homola, J., and Idris, H., "Urban Air Mobility Airspace Integration Concepts and Considerations," 18th AIAA Aviation Technology, Integration, and Operations Conference. Paper 2018-3676, June 2018.

[4] https://ir.jobyaviation.com/news-events/press-releases/detail/22/joby-aviation-announces-upcoming-aircraft-certification

[5] FAA Concept of Operations V1.0 Urban Air Mobility (UAM), Federal Aviation Administration, Washington, D.C., 2020.

[6] UAM Vision Concept of Operations (ConOps) UAM Maturity Level (UML) 4, Version 1.0," NASA, https://ntrs.nasa.gov/citations/20205011091.

[7] Levitt, I., Phojanamongkolkij, N., Witzberger, K., Rios, J., Cheng, A., "UAM Airspace Research Roadmap", https://ntrs.nasa.gov/citations/20210019876, September 2021.

[8] Keeler, J., Verma, S., and Edwards, E., "Investigation of Communications Involved in Near-term UAM Operations," 38th IEEE/AIAA Digital Aviation Systems Conference, Paper 2018-3676, September 2019.

[9] Keeler, J., Verma, V., Dulchinos, V., Wood, R., "Development of Near-term Urban Air Mobility Routes and Airspace Integration", NASA/TM-20210024606, December 2021.

[10] Verma, S. A., Keeler, J., Edwards, T., and Dulchinos, V., "Exploration of Near-term Potential Routes and Procedures for Urban Air Mobility," AIAA Aviation 2019 Forum, Paper 2019-3624, June 2019.

[11] Verma, S., Monheim, S., Moolchandani, K., Pradeep, P., Cheng, A., Thipphavong, D., Dulchinos, V., Arneson, H., and Lauderdale, T., "Lessons Learned: Using UTM Paradigm for Urban Air Mobility," DASC Virtual Event, October 2020.

[12] Goodrich, K.H., Theodore, C.R, "Description of the NASA Urban Air Mobility Maturity Level (UML) Scale", Paper 2021-1627, AIAA Scitech 2021 Forum, January 2021.

[13] Federal Aviation Administration (2014b). FAA Order JO 7110.65V. Air Traffic Control. Washington, DC: Federal Aviation Administration: Department of Transportation.

[14] Verma, S., Dulchinos, V., Wood, W., Farrahi, A., Mogford, R., Ghatas, R., Shyr, M., Design and Analysis of Corridors for UAM Operations, DASC 2022, In Press.

[15] Vascik, P, and Hansman, R., "Allocation of Airspace Cutouts to Enable Procedurally Separated Small Aircraft Operations in Terminal Areas," AIAA Aviation 2020 Forum Virtual Event, Paper 2020-2905, June 2020.

[16] Bulusu, V., Sridhar, B., Cone, A.C, Thipphavong, D., "Analysis of Interactions Between Urban Air Mobility (UAM) Operations and Conventional Traffic in Urban Areas: Traffic Alert and Collision Avoidance (TCAS) Study for UAM Operations", Paper 2019-3521, AIAA Aviation 2019 Forum, June 2019.