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Development of Near-term Urban Air Mobility Routes and Airspace Integration

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Abstract

Growing interest in Urban Air Mobility (UAM) has been demonstrated by a great deal of investment in related research made by industry, government, and academia. Based on this research effort along with considerations of the maturing concept for UAM airspace integration, a cognitive walkthrough exercise and a human-in-the-loop simulation were conducted with controller subject matter experts (SMEs) to evaluate Dallas-Fort Worth (DFW) current day helicopter routes for near-term use as UAM routes. One of the outcomes of this work is a set of heuristics that should be applied when designing UAM routes in the future. The following heuristics were identified as critical to UAM route design: the proximity of routes to surrounding airports (including approach and departure paths of traditional commercial traffic), the configuration of surrounding airports, avoiding congested or heavily populated areas, avoiding route segments that would go through several sectors, avoiding route segments that would go in and out of Class B airspace, creating routes outside of Class B airspace when able, using routes with two-way, altitude-separated traffic when able, minimizing the length of the route, avoiding commonly placed Temporary Flight Restrictions, and creating Non-Movement Areas or UNICOM Areas. This paper describes each of these identified heuristics and relevant examples based on a human-in-the-loop study conducted using the DFW area airspace.

1. Introduction

Recently, there has been a deluge of new airspace concepts seeking integration into the National Airspace System (NAS), including deployment of new emerging airspace management technologies and unmanned aircraft operations. As the NAS continues to evolve, industry, government and academia are researching ways to expand flight mobility services and are developing an airspace concept known as Urban Air Mobility (UAM). The concept centers around the usage of electric Vertical Takeoff and Landing (eVTOL) vehicles for air taxi service. Operations are likely to occur in metropolitan areas that will require UAM flights to access and be integrated with traditional air traffic in controlled airspaces, such as Classes B, C and D [1, 2]. This movement towards developing UAM operations and associated procedures has birthed a plethora of concepts of operations (ConOps) and market studies by industry, government, and other organizations. Some recent efforts include a market study conducted by Booz Allen Hamilton [3] and ConOps development by the MITRE Corporation [4], Federal Aviation Administration (FAA) [5], Wisk, Aurora Flight Sciences, Joby Aviation, and Airbus.

In order to create a common framework for reference, NASA established the UAM Coordination Team which generated a proposed roadmap that characterizes how UAM operations may evolve over time, otherwise known as the UAM Maturity Level (UML) scale [6]. Each level of the UML scale is tied to specific state goals and defining characteristics. The stages are split into three parts 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 occurs prior to commercial operations to cover any last evaluations and field testing before more widespread deployment. The second stage under the “Initial State” known as UML-2, is described as “Low Density and Complexity Commercial Operations with Assistive Automation.” It is expected that CFR 14 Part 61 in the powered-lift category will provide the requirements for pilot certification in UML-2. Operations are expected to comply with current airspace rules and regulations as with a Part 135 air carrier certificate. Operations would be conducted under Visual Flight Rules (VFR) along with a hybrid pairing of Part 135 and 91 requirements. Operations would be low in density meaning that only up to 100 flights would be occupying the airspace at any given time in a utilized metropolitan area. Flights would be point-to-point from UAM vertiports located within the metropolitan area. A given operational environment may have only up to 10 vertiports in the “Initial State” for UAM operations. Beyond the initial UMLs, operations are depicted as being higher in density, having specific airspace corridors for routing, traversing conditions beyond visual meteorological conditions, and having a higher level of autonomous systems both onboard the aircraft and, on the ground [6].

Although the UML framework and other ConOps generated by the larger aviation community provide general roadmaps and visualizations for the future of UAM operations, questions still exist regarding some of the near-term operational challenges of UAM, such as the integration of UAM into existing airspace operations. The utilization of existing airspace and procedures for the “Initial State” or near-term UAM operations have been discussed as likely being on the receiving side of typical ATC services and following established helicopter routes, since operations will be relatively similar to those conducted by helicopter companies in areas such as Dallas-Fort Worth, Texas, and New York City [1]. However, there exist potential barriers to adding additional air traffic management workload and airspace density, onto pre-existing airspace operations. Research is currently being conducted to examine the feasibility of such integration and its impact on the airspace environments.

This paper explores potential near-term UAM routes and procedural heuristics developed through a cognitive walkthrough and human-in-the-loop (HITL) experiment. These routes and heuristics could be applied in the near-term to allow integration of UAM flights into the current National Airspace. The purpose of this exploration was to help identify operational constraints and capabilities in current day helicopter operations within the Dallas-Fort Worth metropolitan area, mainly in south flow configuration. The paper will discuss the general constraints of the airspace, current day helicopter operations, the routes and heuristics identified through collaborative efforts, and conclude with a discussion of future research and goals.

2. Dallas-Fort Worth Airspace

The greater Dallas-Fort Worth metropolitan area includes three major airports of interest for potential UAM operations, including Dallas-Fort Worth International Airport (DFW), Dallas Love Field Airport (DAL), and Addison Airport (ADS). All airports in the DFW area sit around 600 feet above mean sea level (MSL). Both DFW and DAL are Class B airports, whereas ADS exists within Class D airspace. Additional surrounding airspaces include Classes G and E. In Figure 1, sectors corresponding to the different airports are represented by color with DFW’s sectors appearing in green, DAL’s sectors appearing in purple, and ADS’s sectors appearing in yellow. In total, the DFW area airports contain four major approach streams and four departure streams with DFW airport, which is the largest number of streams an airport can have (see Figure 2). Between government fiscal years 2009 and 2017, average daily operations for commercial aviation operations at DFW alone ranged from 2,135 and 2,369 with the peak occurring in 2016 [7]. A brief overview of operational procedures for each airport will be included in the following sub-sections. For the purposes of this paper, all altitudes will be discussed in feet MSL with the assumption that the feet Above Ground Level (AGL) would be roughly an offset of 600 ft between MSL and AGL based upon the average elevation observed in Dallas-Fort Worth airspace. For example, a route assuming to be 1,600 ft MSL would be 1,000 ft AGL.

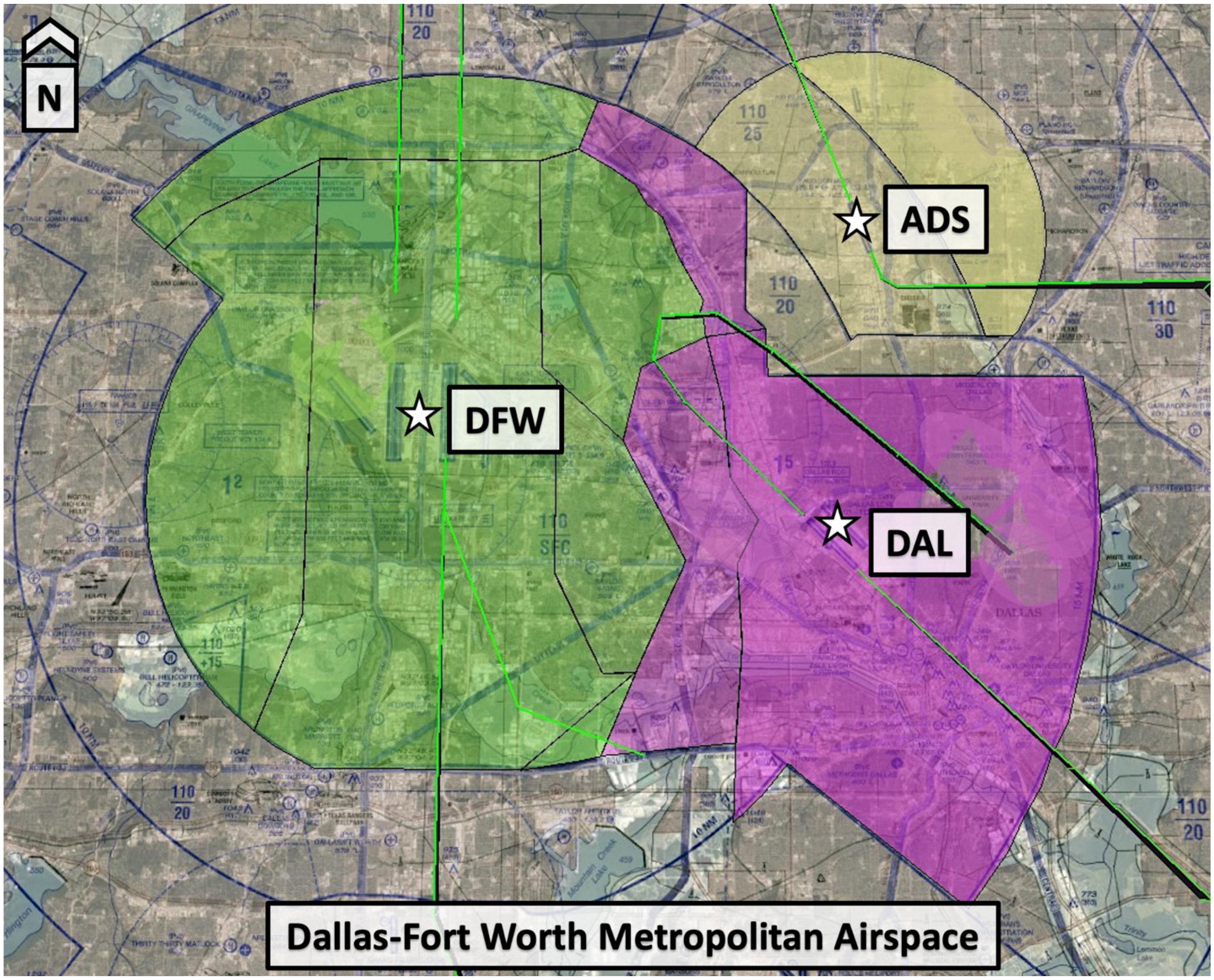

Figure 1. Overview of segregation of airspace classes within the DFW metropolitan area. Polygon colors represent sector ownership, with green representing DFW, purple representing DAL, and yellow representing ADS.

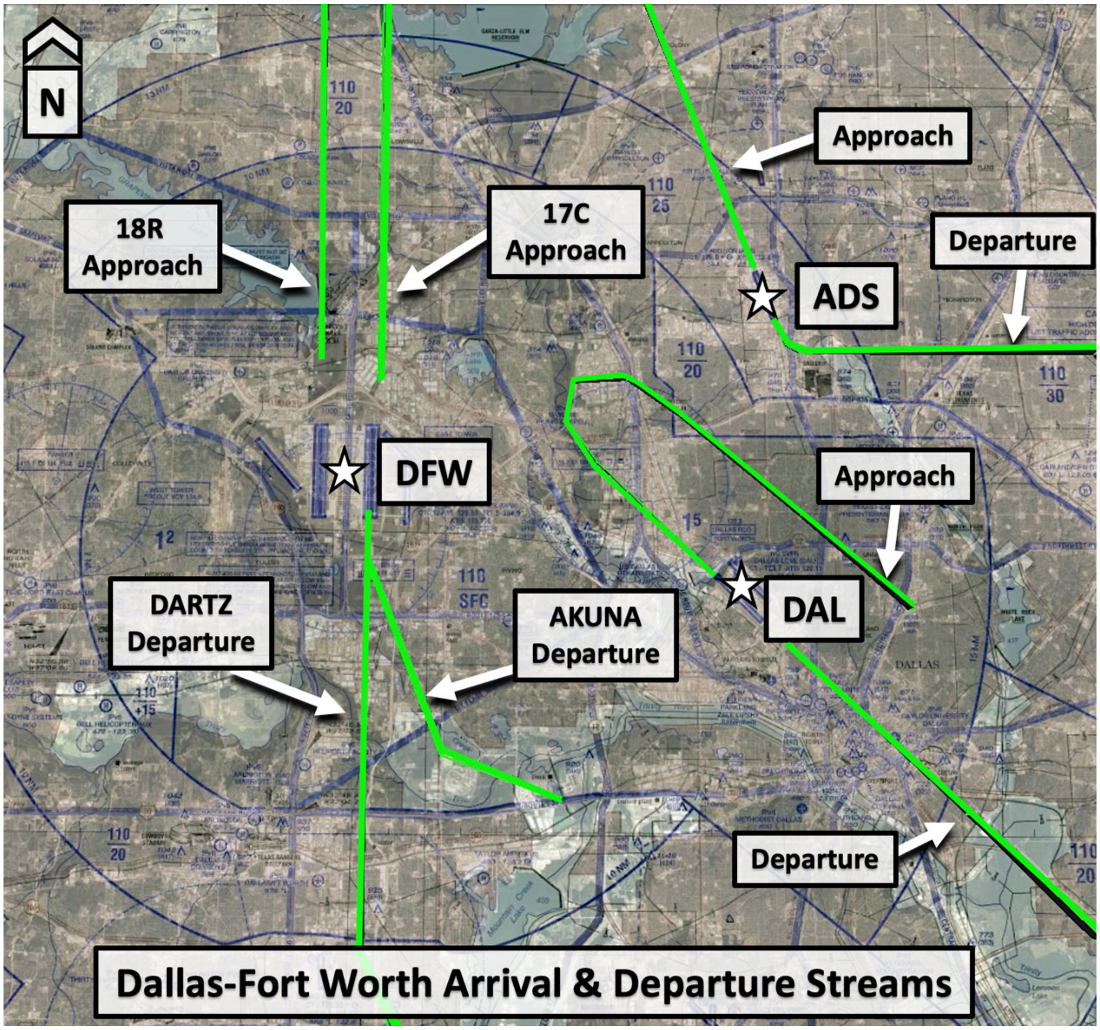

Figure 2. Overview of segregation of airspace classes within the Dallas-Fort Worth metropolitan area, featuring the approach and departure paths in south flow runway configuration for DFW, DAL, and ADS.

2.1 DFW Airport (DFW)

DFW airport handles around two thousand air traffic operations per day. Airspace for DFW reserved for VFR operations covers surface level to 1,400 ft MSL within the west portion of DFW's airspace. An additional 100 ft MSL is added on to the cap for VFR reservation to include Special VFR operations. In south flow configuration, primary arrival runways include 17L, 17C, 18R, and 13R. Primary departure runways include 17R and 18L (see Figure 3). Runway 13L is sometimes used in the event where other runways are unavailable for departing jet aircraft (e.g., in severe weather). Departures off Runway 13L require coordination and approval from Dallas Terminal Radar Control (D10) Traffic Management Unit (TMU).

The south flow configuration has disadvantages during hot weather, including inadequate rate of climb for heavier jets and a higher rate of "potential satellite departure conflicts" [7, p. 72]. ATC complexes at DFW are divided into east and west by Spine Road, otherwise known as an "imaginary line that runs indefinitely north to south along International Parkway through the middle of DFW airport" [7, p. 21]. The East Complex monitored by the East Tower Controllers provides support for runways 18R, 18L, and 13R. The West Complex monitored by the West Tower Controllers oversees runways 17R, 17C, 17L, and 13L.

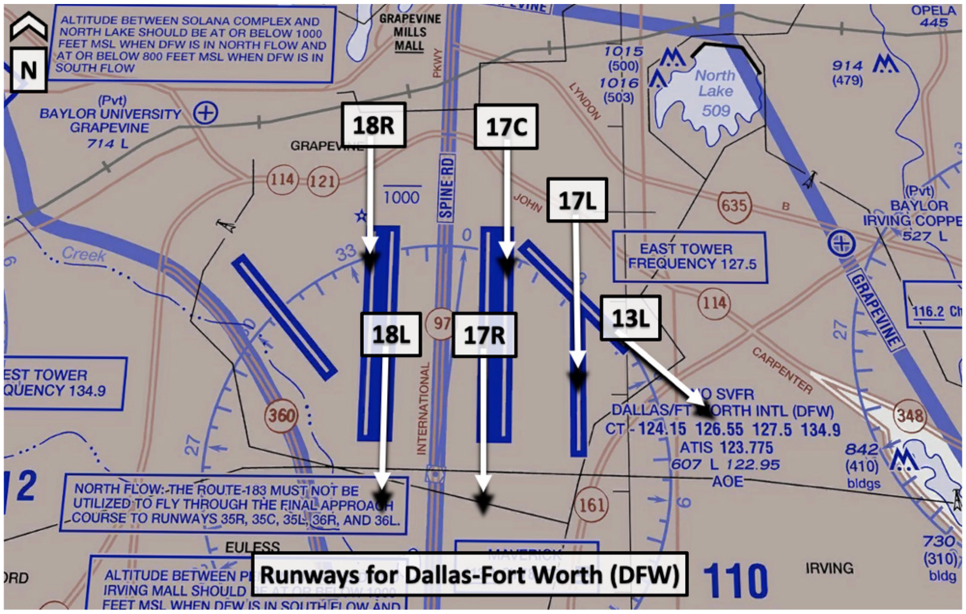

Figure 3. Active runways for DFW in South Flow configuration.

2.2 DAL Airport (DAL)

Active runways at DAL consist of 13L, 13R, 31R, and 31L in south flow configuration [8] (see Figure 4). Positions at DAL include Local Control and Local Control North, otherwise known as the helicopter position (e.g., Helo). Local Control is responsible for all runways and separating aircraft within the surface level to 2,000 ft MSL [8]. When south flow configuration is active: "Local Control is allowed automatic releases from Local Control North for VFR aircraft remaining in DAL Class B airspace or departing DAL in accordance with the D10/DAL Letter of Agreement" [8, p. 25]. Local Control North or the Helo position is responsible for handling all aircraft above 2,000 ft MSL.

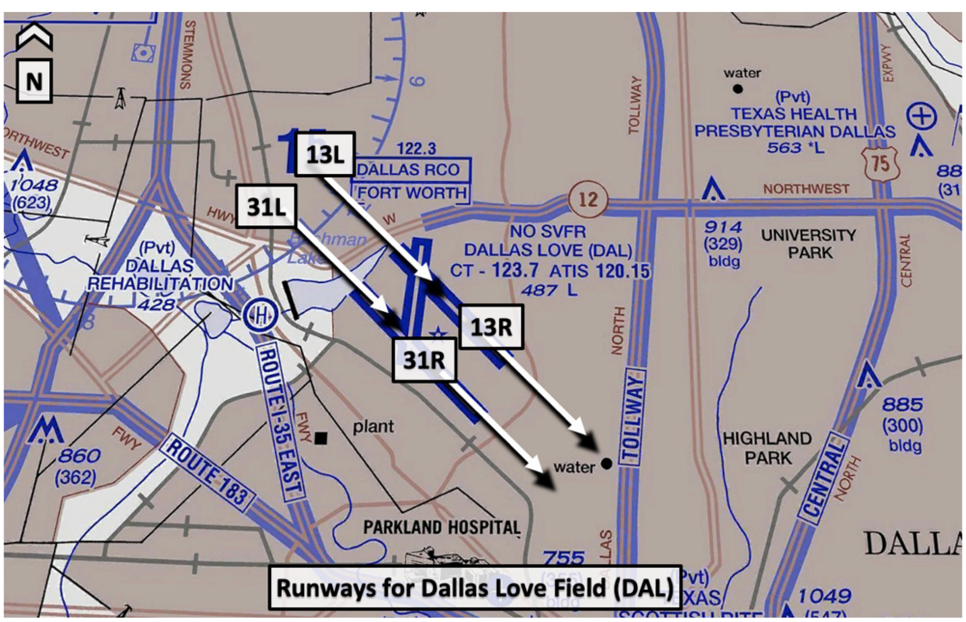

Figure 4. Active runways for DAL in South Flow configuration

2.3 ADS Airport (ADS)

Addison operates as a Class D airport, controlling the airspace from surface level to 3,000 ft MSL and typically features under 300 flight operations per day. The airport consists of a single runway (i.e., runway 15/33) and has only one Local Control position that monitors the airport's arrivals, departures, and VFR transitions. Runway 15 acts as the departure runway, whereas runway 33 acts as the arrival runway (see Figure 5).

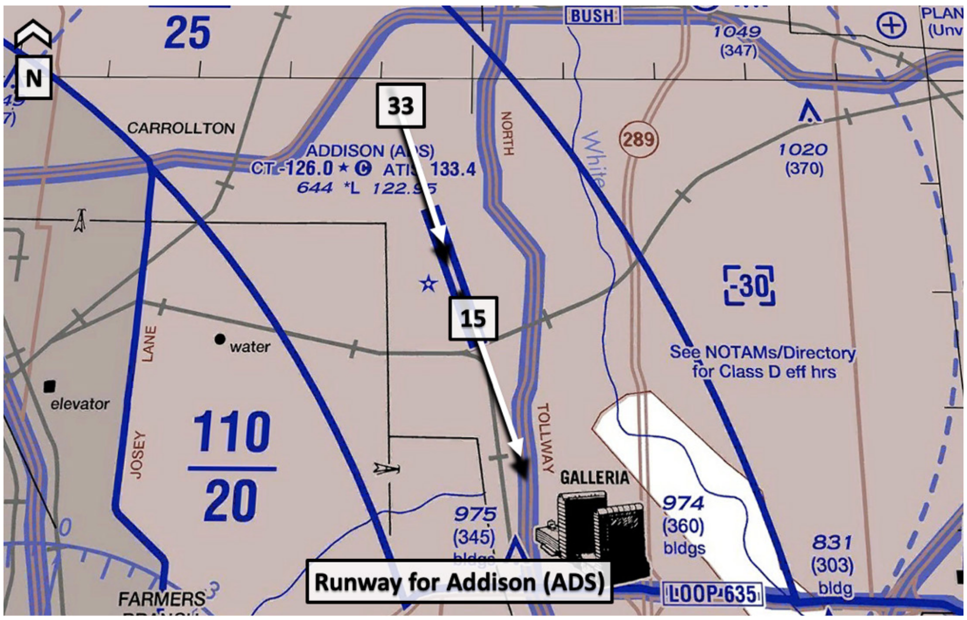

Figure 5. Active runways for ADS in South Flow configuration

2.4 Current Helicopter Operations

The current day helicopter routes within the DFW area are generally set along prominent highways for visual reference and consistency, including Route 183, Route I-30, North Dallas Tollway, and Central Expressway. Each segment of route is named after a particular freeway that it follows or a notable landmark and is visually labeled in the published charts. A selection of routes in south flow configuration, as outlined in the existing DFW letter of agreement (LOA) between the relevant airspace authorities and helicopter operating parties, can be seen in Figure 6. Some constraints are placed on the routes depending on the flow configuration in place. For example, in south flow, the Grapevine, or a section of routing that lies near the boundary between DFW and DAL airspaces, "must not be utilized to fly through the final approach course" to runways 17L, 17C, 17R, 18L, and 18R [8, p. 159].

If a helicopter approaches north of DFW, the flight will be brought through Vista Ridge, a route section that flies north of and parallel to DFW airport, to Spine Road, which divides the runways at DFW, in order to fly the approach into DFW. If approaching from south of DFW, flights are routed through Route 183, which runs south of and parallel to DFW, to intersect with the Spine Road to fly the approach into DFW. Flights along Spine Road are more than 2500 ft in distance from the centerline of the inner runways (17R/35L and 18L/36R) at DFW, not requiring any wake turbulence advisories to the helicopters or traditional traffic. These flights along Spine Road "must remain in direct communication" with the LE-1 or LW-1 controllers, "unless otherwise directed by" the front-line manager or the commander in chief. [7, p. 160]. Movement areas at DFW are available to helicopters for both landing and departing. Additional restrictions can also include cruise altitude restrictions and placements of Temporary Flight Restriction

(TFR) zones. For example, as per the helicopter route chart published, all flights crossing route 183 need to be held at or below 1,000 ft MSL to provide adequate vertical separation from flights utilizing the AKUNA or DARTZ departures at DFW.

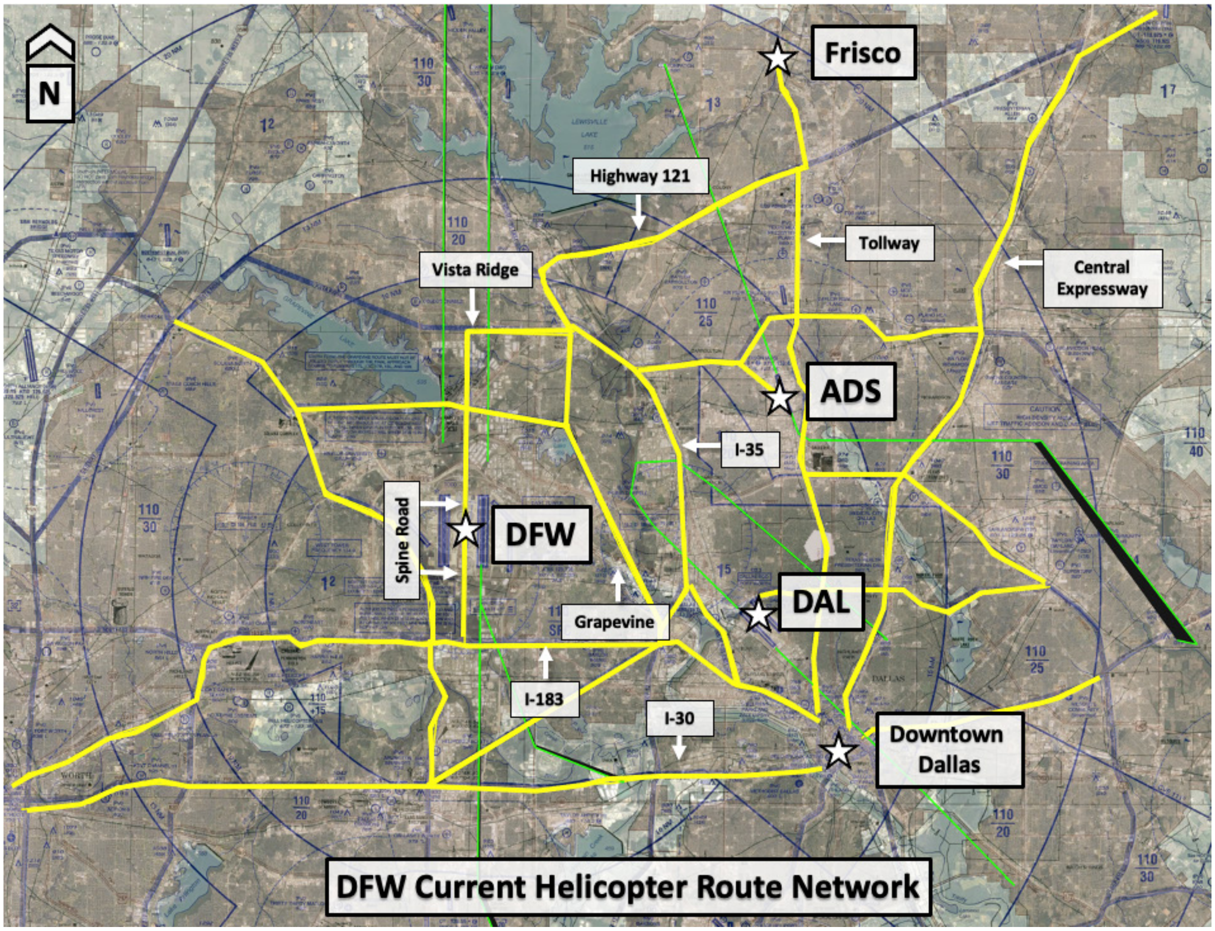

Figure 6. Overview of current day helicopter routes in DFW.

The communications for helicopter routes in the DFW area follows similar current-day procedures for accessing classes of airspace where the helicopter pilot contacts local air traffic control to receive permission to enter the Class B or D airspace. This exchange happens prior to the intended entrance and the pilot must provide the full planned route or general intent of the flight. The controller is required to either accept or reject the flight's request to enter the airspace. If the controller accepts the flight, he or she will assign a unique beacon code to the aircraft, provide a read back of the entire route clearance, and ensure that the helicopter remains clear of traditional traffic and follows procedures outlined in the LOA. The controller may make traffic calls for wake turbulence or for notice of other traffic to the helicopter pilot and traditional traffic when required. Handoffs are made between facilities at normal transition points with typical verbal communication.

3. Methods

In order to assess operational fit and identify potential constraints for UAM operations in the DFW area, a first iteration of a potential UAM route network was built around the current DFW helicopter routes. The UAM route network was analyzed by researchers in order to identify areas that may be constrained or require changes for future UAM operations. Following the initial development and proposed changes to the original helicopter routes for a UAM route network, a cognitive walkthrough and HITL study were completed to gather subject matter expert (SME) feedback and determine whether modified versions of the original helicopter routes successfully address concerns unique to potential UAM flight operations. The following sections briefly outline the methods used for these activities.

3.1 Cognitive Walkthrough

A cognitive walkthrough exercise was conducted at NASA Ames Research Center with several subject matter experts in spring of 2018 prior to execution of the HITL. This included a total of four SMEs with expertise as controllers at either DFW or DAL, including the DFW LE-3 and DAL Local controller positions. The objectives of the exercise were to:

- Evaluate the current helicopter routes in DFW airspace for UAM operations
- Define procedures for accessing Class B, C, and D airspace
- Evaluate modifications made to the original routes and operational procedures
- Evaluate roles and responsibilities for controllers with regard to managing UAM flights
- Define low, medium, and high levels of UAM traffic

Individual walkthroughs were conducted with each SME separately and the entire exercise took place over several days. SMEs were briefed on the overall characteristics of the UAM project and proposed concept of operations. This included details regarding the purpose of UAM (e.g., advanced, intra-metro air mobility), proposed tenets for UAM operations, UAM mission profiles, possible challenges for operations, and possible evolutions of UAM operations. Following the project briefing, an overview of current helicopter routes within the DFW area was presented with possible modifications for UAM operations. SMEs were asked scripted questions to elicit feedback, but were also able to openly give feedback through the entire process. Following the conclusion of the cognitive walkthrough, researchers used the SME feedback to make changes to the proposed UAM route network. Some of these changes will be discussed in the following section and how they affected individual routes.

3.2 HITL Simulation

In September of 2018, as a follow on to the cognitive walkthrough exercise conducted in the spring of 2018, a HITL simulation further explored the acceptability of the developed UAM route network and proposed near-term operational procedures. The HITL simulation incorporated lessons learned from the cognitive walkthrough and focused on facilitating the integration of UAM flights within Class B, C, and D airspace. The main variables of interest in this simulation were traffic level and operational procedure set. Traffic levels were low, medium, and high density. The operational procedure sets also featured three levels. The first condition featured current DFW helicopter routes and followed current-day communications, and in the second condition, alternate means of communication were established via an LOA. The LOA established procedures intended to cut down on verbal communications (e.g., establishing route codes or names, eliminating the need to provide explicit Class B clearance). The third condition featured the same LOA in conjunction with the modified versions of the original helicopter routes that were tailored for UAM operations (see Table 1). Only data referring to feedback on the routes collected during the HITL will be discussed here. For a detailed description and discussion of the results from the HITL, please see referenced papers [10, 11, 12].

3.3 Assumptions

The following analysis follows basic assumptions regarding the type of UAM operations that would be required for early operations within the DFW area. It is assumed that operations would be under Visual Flight Rules (VFR) within Visual Meteorological Conditions (VMC).

Operations are also assumed to be occurring with south flow configuration for DFW. Aircraft being used for such operations would include electric vertical takeoff and landing (eVTOL) rotorcraft.

4. Analysis of Potential UAM Routes around DFW

Based on the lessons learned from the cognitive walkthrough and subsequent HITL simulation, a number of heuristics used to develop the modifications to the proposed UAM route network based upon the current DFW helicopter routes were identified. These heuristics include the following:

- Proximity to airport
- Configuration of surrounding airports
- Heavily congested or populated areas
- Flights through multiple sectors
- Transitioning in and out of Class B airspace
- Creating routes outside of Class B airspace
- Designing two-way routes with vertical separation
- Minimizing route length
- Commonly placed Temporary Flight Restrictions (TFRs)
- Creating non-movement areas or universal communication (UNICOM) areas

Each heuristic will be described in more detail and will be accompanied by a relevant example from the UAM routes developed for the DFW area.

4.1 Proximity to Airport

When designing UAM routes it is important to account for the proximity of routes to surrounding airports, including approach and departure paths of traditional commercial traffic. Adequate separation must be provided if it is necessary for UAM routes to cross through either an arrival or departure route to land at a specific airport. As per JO 7110.65, separation between traditional traffic and UAM traffic is required to be 2,500 ft lateral or 1,000 ft vertical to avoid wake turbulence advisories provided by the air traffic controller to the traffic. The other criteria that ATC need to apply is 1.5 nautical miles (nmi) lateral or 500 ft vertical for separation between UAM aircraft (e.g., helicopters) and any other traditional aircraft whose weight is greater than 19,000 pounds. Such separation should consider potential contingency events (e.g., lower than normal approaches or takeoffs) for the traditional aircraft flying such paths.

For example, the current helicopter routing from Frisco, a city located northeast of DFW (see Figure 7), to DFW crosses through at least one arrival stream via Vista Ridge in order to land at DFW along Spine Road. Proposed UAM operations assume that the approach on Spine Road between two active DFW runways would only allow for one-way traffic (i.e., only incoming arrival UAMs and no UAM departures at any time during south flow configuration) due to the proximity to both arrival paths for runways 17R/17C and 18R/18L. Arriving UAMs would fly at 1,100 ft MSL under the final approach fixes for runways 17R/17C. Two approach fixes for 17R/17C include ZINGG, where traditional aircraft are expected to be at 3,000 ft MSL and JIFFY, where aircraft are expected to be at 2,300 ft MSL. UAM aircraft would fly just under JIFFY with about 1,200 ft MSL separation from traditional arriving aircraft at DFW. Internal discussions amongst the research team revealed that flying under JIFFY with this separation was possible, but potential operations could not take more than three to four UAM flights at any given time in order to ensure safety and separation between the multiple flows of traffic (see Figure 8).

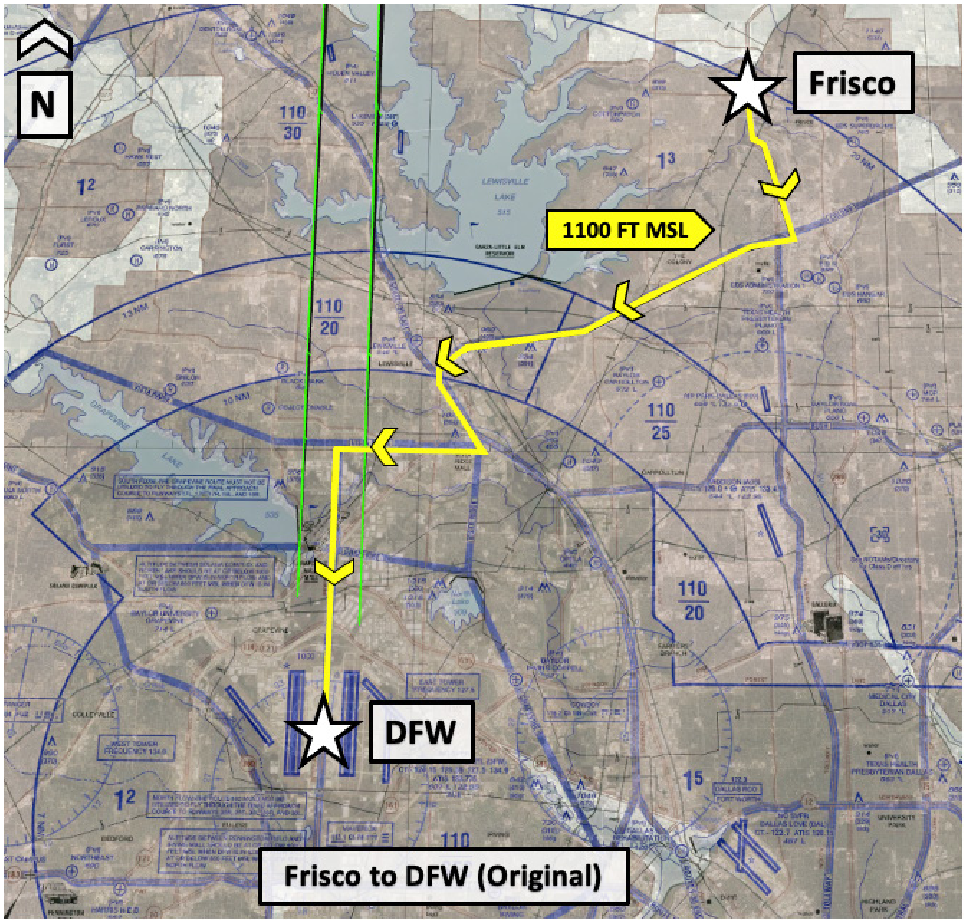

Figure 7. Overview of current helicopter routing from Frisco to DFW.

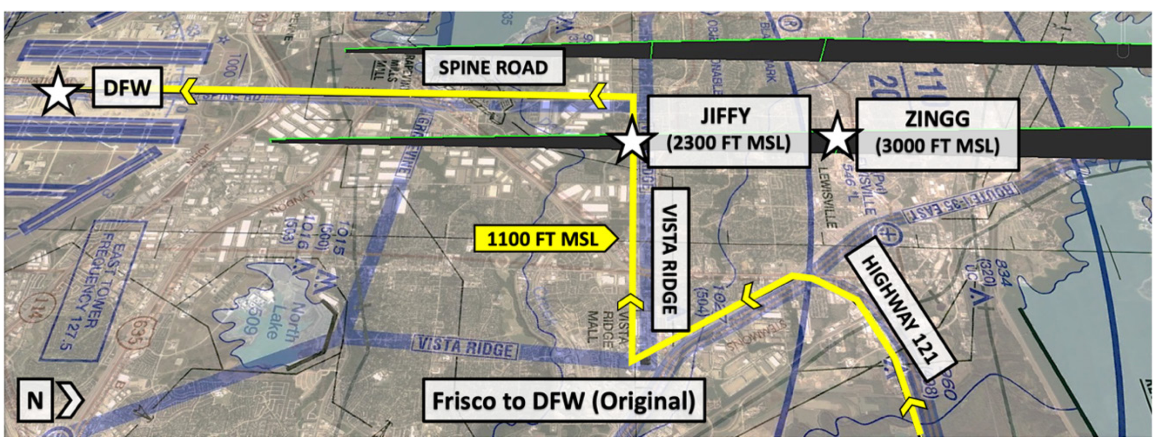

Figure 8. Current helicopter routing from Frisco to DFW near arrival paths for DFW.

Taking into account internal research team feedback, a proposed change to the original route was identified to provide additional separation between UAM and traditional approaches for 17R/17C. This change aimed at alleviating some of the ATC workload concern of having less separation between flight paths and sought to accommodate greater flows of UAM traffic than one or two at a given time. This change pushed the original route portion along Vista Ridge back from the final approach fix of JIFFY by four miles. Lateral separation from ZINGG was now

1.8 miles. During the cognitive walkthrough tasks, SMEs gave additional feedback that separation could still be achieved while reducing the trajectory flown if UAM aircraft were to fly through ZINGG instead of flying behind the crossing fix (see Figure 9).

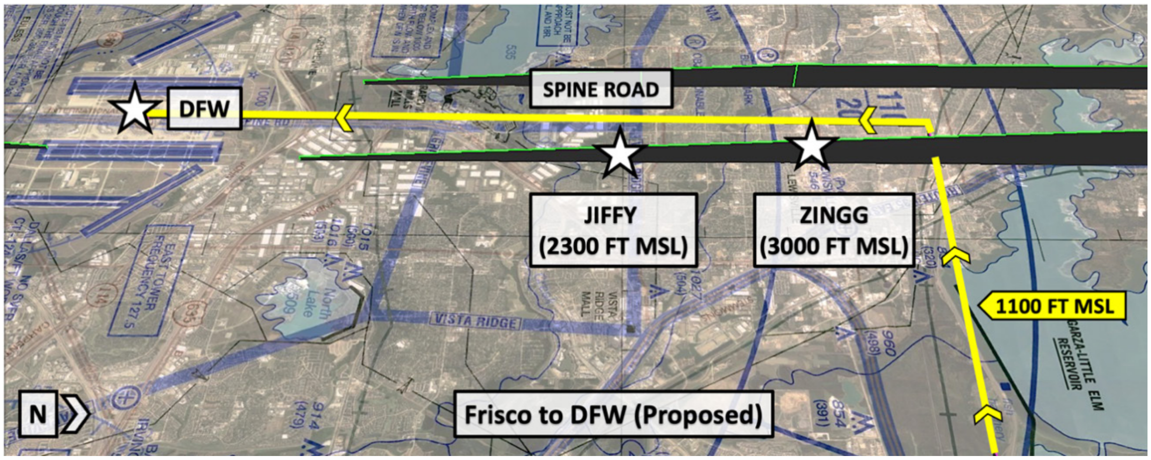

Figure 9. Proposed routing for UAM operations from Frisco to DFW.

Following the advice received from SMEs during the cognitive walkthrough exercise, the modified version of the Frisco to DFW route used for the HITL simulation pushed the route segment before Spine Road closer towards Vista Ridge and just before the crossing fix ZINGG (see Figure 10). UAM flights now had a cruise altitude of 1,600 ft MSL instead of the original 1,100 ft MSL. Incoming flights would be at 3,000 ft MSL and have a separation of 1,400 ft MSL from UAM traffic. This provided a greater separation than with the original, current helicopter route version which had a separation of 1,200 ft MSL. This move also reduced the trajectory flown by roughly 1 mile or .87 nmi.

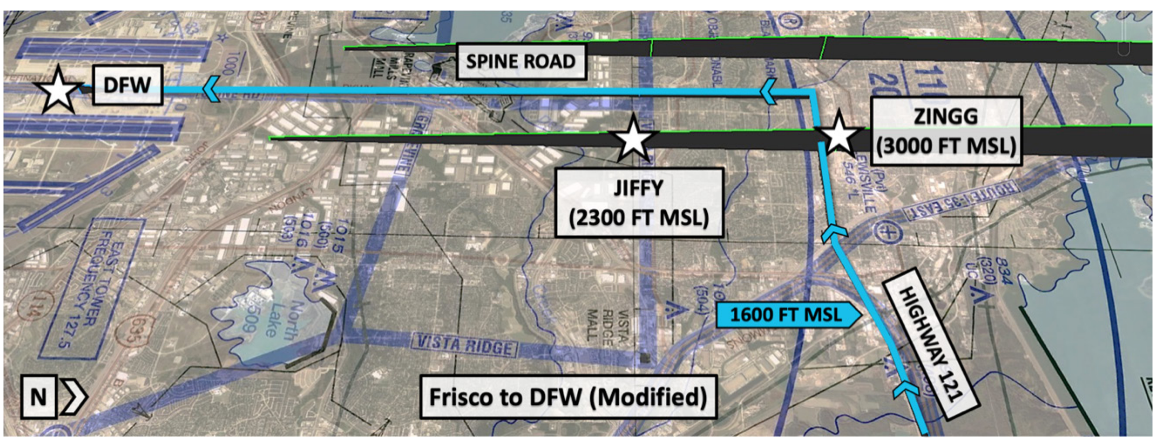

Figure 10. Modified version of the approach into DFW for the Frisco to DFW route.

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4.2 Configuration of Surrounding Airports

When designing UAM routes around airports, commercial air traffic routes and airport configurations should be considered. The south flow airport configuration was the focus of the cognitive walkthrough and the HITL. Under DFW's current south flow configuration, the original helicopter routes departing from DFW and going to Frisco involved parts of Spine Road (south side), Route I-183, Grapevine, and Highway 121 (see Figure 11). However, in the south flow configuration, usage of some routes may not feasible due to conflicts with approach and departure streams for DFW and DAL.

At DFW, two major departure streams (i.e., AKUNA and DARTZ) are close to Route I-183, which runs East-West, and is south of DFW. This route segment is 2.7 miles from the associated runways at DFW. The AKUNA departure stream typically features a climb to an altitude between 2,800 ft and 3,000 ft MSL above Route I-183. Flights along Route I-183 would be at altitude of 1,000 ft MSL due to active altitude restrictions for the current published helicopter routes. However, vertical separation could be minimized between departing heavy jets and potential UAM flights both outbound from DFW during summer months. Higher temperatures and humidity drastically decrease the climb rate of bigger jets and run the risk of having departures at lower than published altitudes.

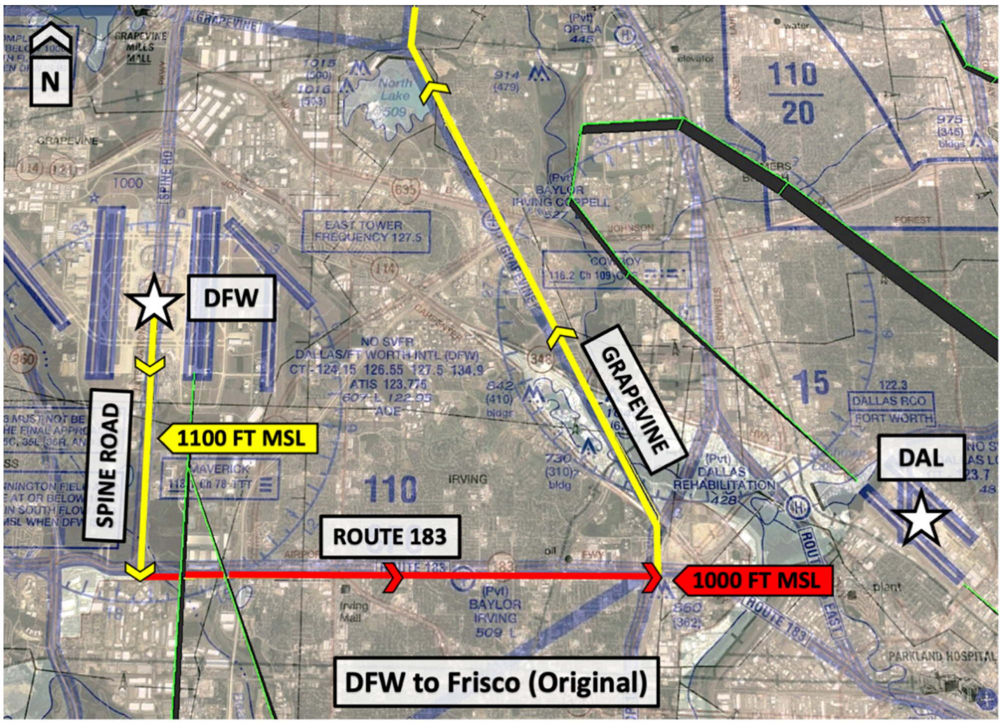

Figure 11. Original helicopter route for DFW to Frisco, where usage of the Grapevine route can conflict with DAL arrivals.

Additionally, DAL was thought to have conflicts between arrival streams and potential UAM flights along the Grapevine and Route I-35 East portions (see Figure 12). Arrivals into DAL for runway 13R can approach from either the north or south of DFW. The final approach leg into DAL from either direction crosses over Route I-35 East and is close to the Grapevine route segment, or roughly spaced one mile apart at the closest point.

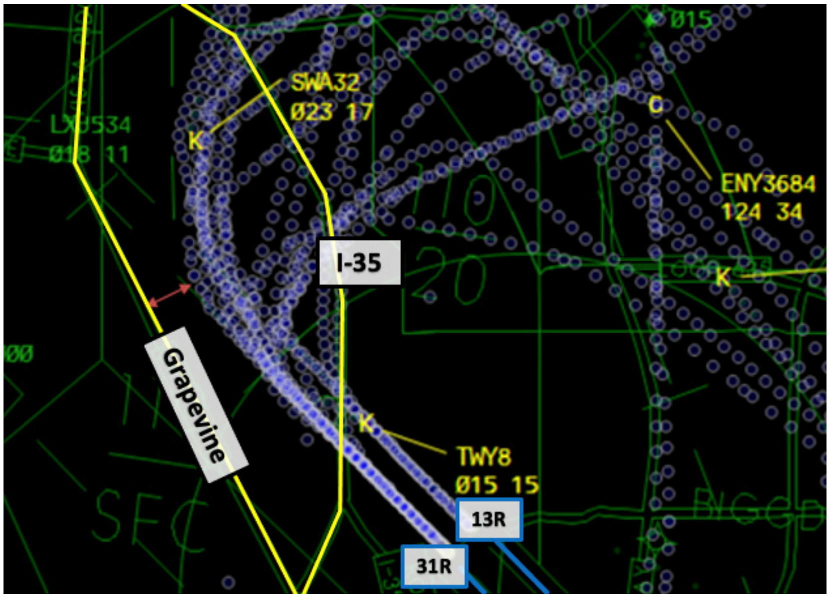

Figure 12. STARS display of track history for arrivals into DAL.

During the cognitive walkthrough, SMEs expressed that Route I-183 could still be usable at 1,000 ft MSL during most seasonal settings outside of summer months, which would require greater coordination and monitoring to ensure safe separation from departing traditional heavy jets and UAM traffic. However, the route would not be workable as a two-way, altitude separated route. Lateral separation was suggested as a feasible implementation to allow for two streams of traffic since vertical separation would not be achievable with the current altitude restriction along Route I-183 (i.e., 1000 ft MSL). Additionally, SMEs indicated the usage of the Grapevine route featured enough vertical separation from arrivals at DFW. SMEs suggested modifying the portion of the Grapevine route segment to be on the boundary with DAL's and DFW's sectors to increase lateral separation from arrivals into DAL and UAM traffic (see Figure 13).

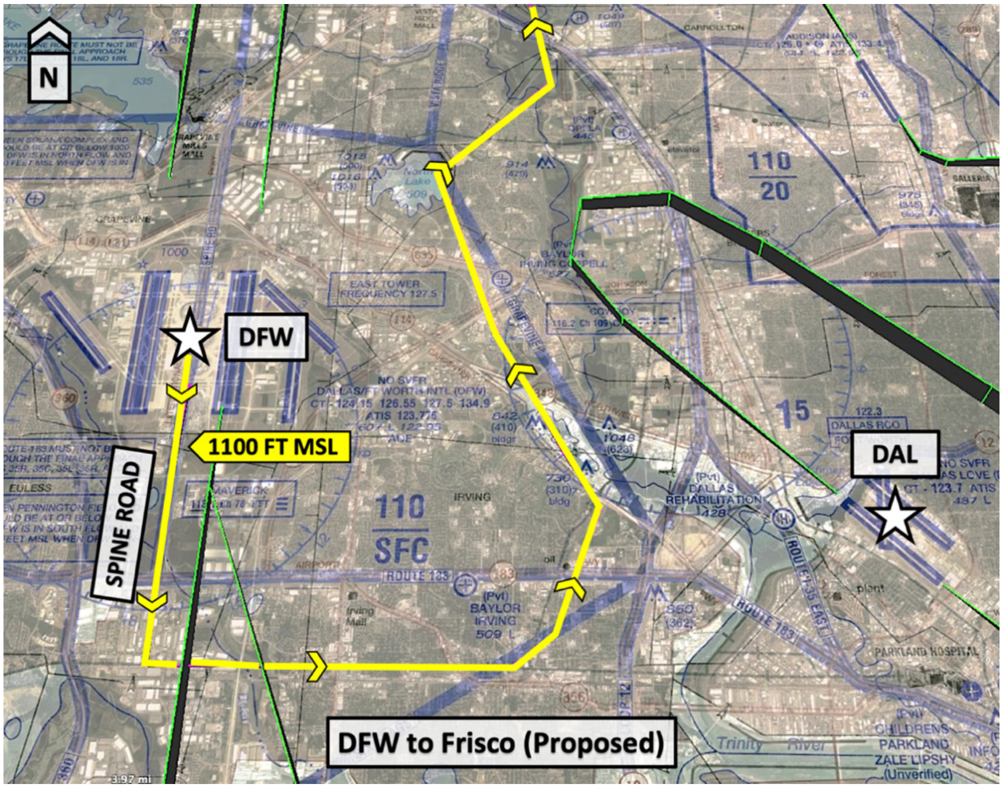

Figure 13. Proposed route for DFW to Frisco.

However, following the cognitive walkthrough an additional method for deconflicting from DAL's arrival stream was found through the usage of the North Belt Line Road, which is available in DFW's south flow configuration. Generally, there is minimal traffic in this area that would conflict with potential UAM flights. In the modified version of the routing from DFW to Frisco, Spine Road's south of DFW route segment is extended past Route I-183 with flights at 1,600 ft MSL. This altitude change was made to test the usage of two-way altitude separated traffic along the Spine Road. Outbound UAM flights from DFW would remain vertically separated from incoming UAM traffic along Spine Road at 1,100 ft MSL. Vertical separation between outbound and inbound traffic would be roughly 500 ft MSL. When nearly parallel with Irving Mall, outbound UAM flights would turn and proceed toward Irving Mall to intersect with the North Belt Line Road. At Irving Mall, UAM flights would turn onto North Belt Line Road and descend to 1,200 ft MSL to give greater separation between incoming and outbound aircraft. Flights would eventually descend to 1,100 ft MSL and reconnect with Highway 121 to proceed to Frisco (see Figure 14).

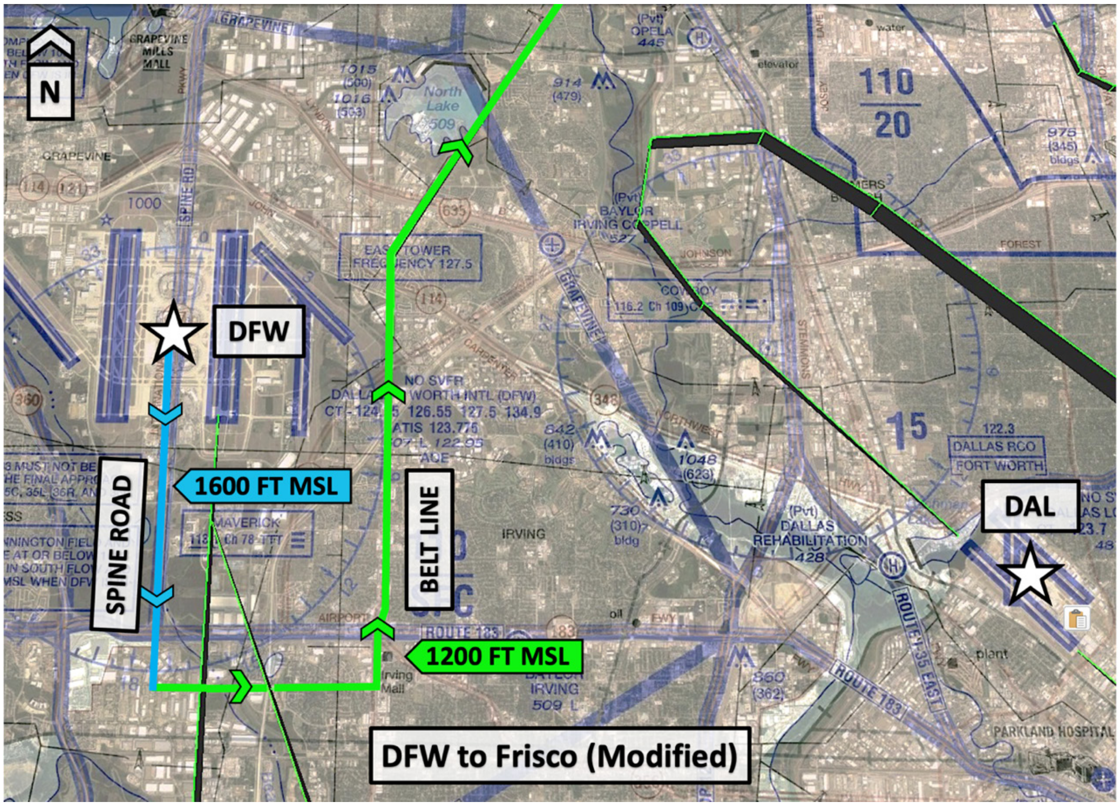

Figure 14. Modified route for DFW to Frisco.

4.3 Heavily Congested or Populated Areas

When designing the proposed DFW UAM route network an attempt was made to avoid populated areas for the purposes of noise abatement, contingency management planning, and general safety. For example, the original helicopter route from Downtown Dallas to DFW followed Route 183 northwest towards the Grapevine at 1,100 ft MSL. UAM flights would then turn onto Vista Ridge to proceed towards the intersection with Spine Road and then follow Spine Road to the vertiport at DFW (see Figure 15).

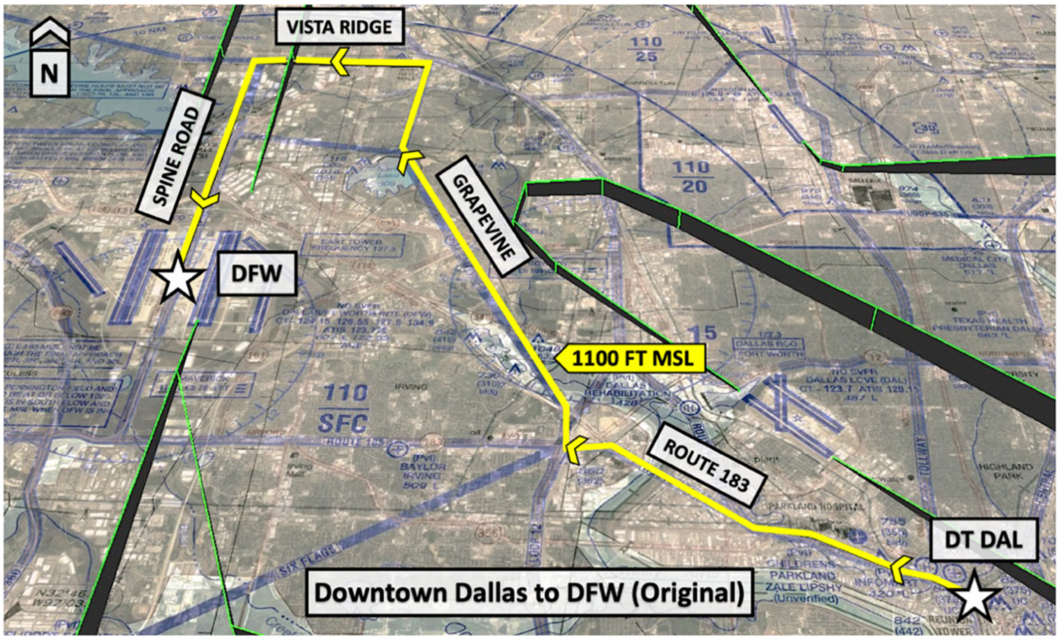

Figure 15. Original helicopter route for Downtown Dallas to DFW.

In order to avoid and limit the density of flights over populated areas just northwest of DAL, routing was eventually moved to follow Trinity River when departing out of Downtown Dallas. Entry into DFW would occur instead via the southside of Spine Road and have flights altitude separated from outbound UAM flights (at 1,600 ft MSL) and traditional traffic. UAM flights would depart from within the Downtown Dallas UNICOM area at 1,100 ft MSL and proceed to Trinity River. Flights would continue along Trinity River, past Loop 12, and towards Six Flags. After Six Flags, flights would turn north and proceed to Spine Road to land at one of DFW's vertiports (see Figure 16). This reduced the number of aircraft would need to follow the Grapevine and Route 183 route segments.

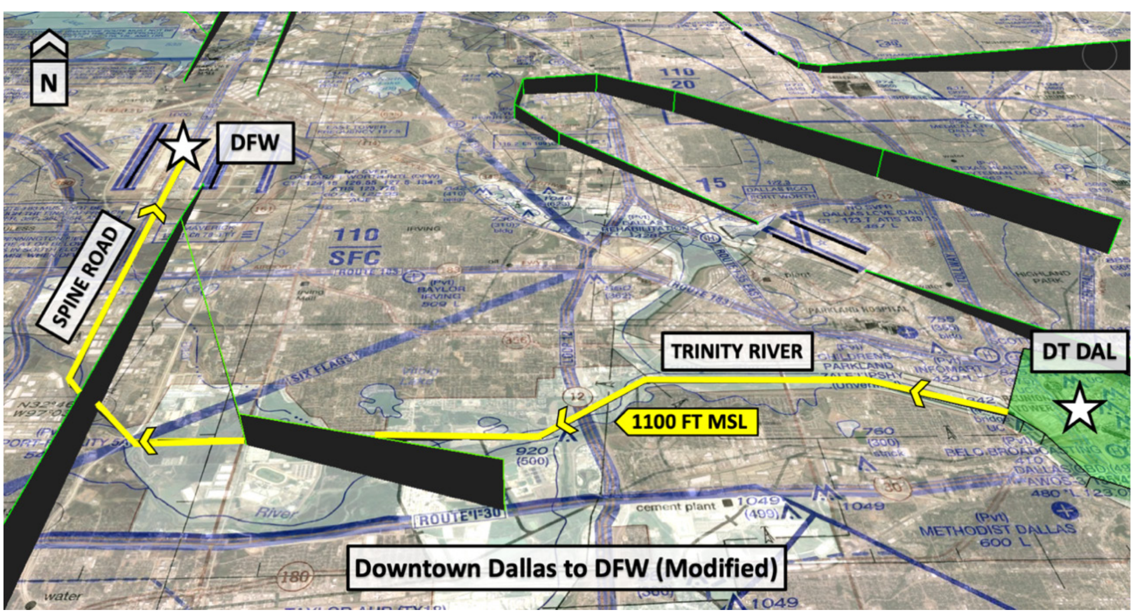

Figure 16. Modified route for Downtown Dallas to DFW following Trinity River.

4.4 UAM Flights Through Multiple Sectors

To avoid the potential need for contacting ATC at sector boundaries for the purpose of handoffs, as in the case of traditional air traffic, whenever possible it makes sense to create routes that avoid crossing in and out of multiple sector boundaries. Having flights cross over into multiple sectors in a short period of time would put unnecessary workload strain for both air traffic controllers and pilots. The original helicopter route departing from DFW and arriving in Frisco violated this proposed guideline. Flights would depart from DFW and follow Spine Road southward towards Route 183. At Route 183, flights would turn left eastward and follow Route 183. Near the intersection between the Grapevine and Route 183, flights would need to be handed off from DFW LE-3 to DAL Local (see Figure 17).

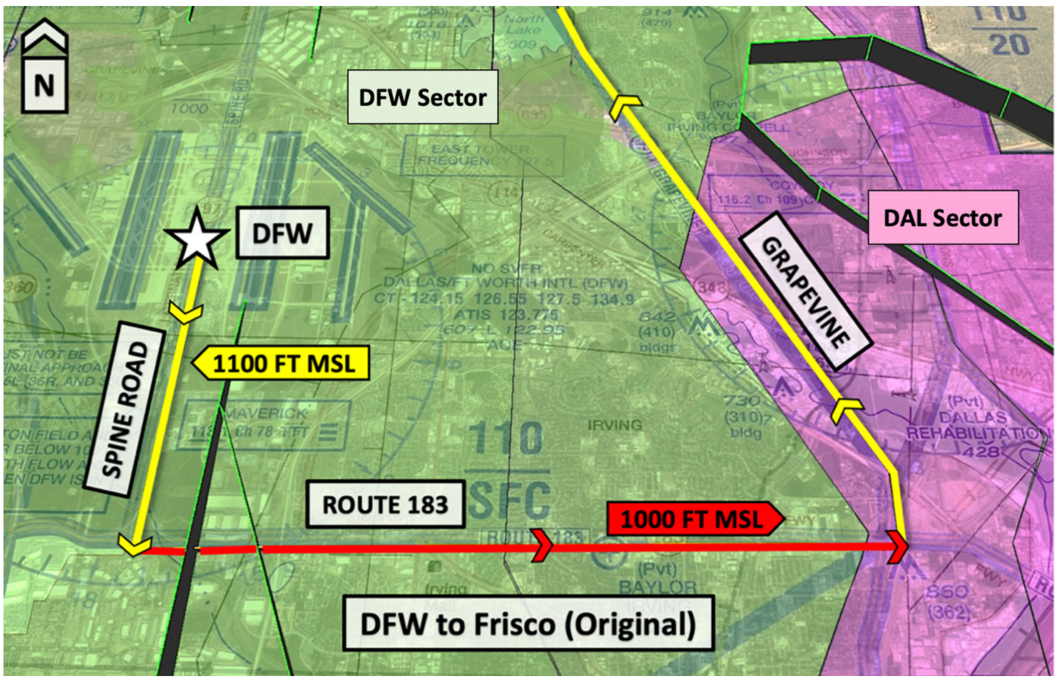

Figure 17. Original helicopter route from DFW to Frisco, which crosses over multiple sectors via the Grapevine, with DFW's sector represented with a green overlay and DAL's sector represented with a purple overlay.

From the cognitive walkthrough, SMEs proposed moving the routing for the Grapevine route towards the boundary between DFW and DAL to avoid unnecessary handoffs between the two sectors. Flights would still depart along Spine Road at 1,100 ft MSL, but would no longer directly follow Route 183 to connect to the Grapevine route. Instead, flights would continue past Route 183 and run parallel to Route 183 by one mile south (or .87 nmi) and maintain the takeoff altitude of 1,100 ft MSL. Flights would turn up towards the Grapevine route and follow along the sector borders for DFW and DAL (see Figure 18). Flights would eventually reconnect with Highway 121 to proceed to Frisco. This would keep the flights within DFW's sector at all times before exiting Class B airspace. However, later conversations about the placement of the route on the boundary between sectors led to its eventual movement more westward in order to avoid callouts and other workload strain issues.

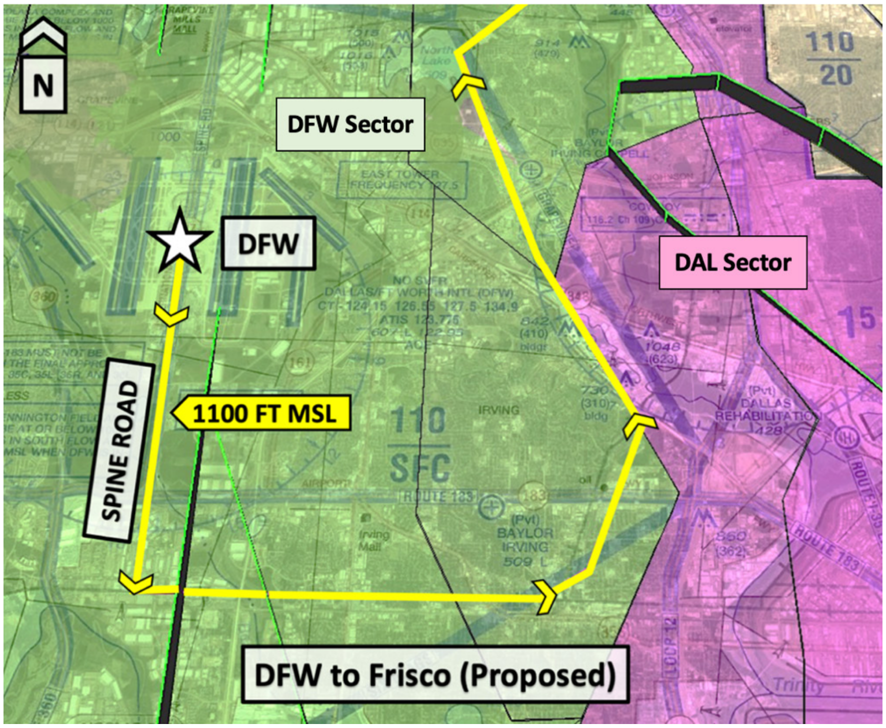

Figure 18. Proposed route from DFW to Frisco with the Grapevine moved towards the sector boundaries for DFW and DAL.

As discussed earlier, prior to the HITL, the route was further modified and pushed the route line even further away from the original Grapevine route and, instead, followed North Belt Line Road. This change reduced the distance flown as well as provided greater distance from the sector borders between DFW and DAL airports and allowed the UAM flight to stay with DFW controller, eliminating the need for handoffs (see Figure 19).

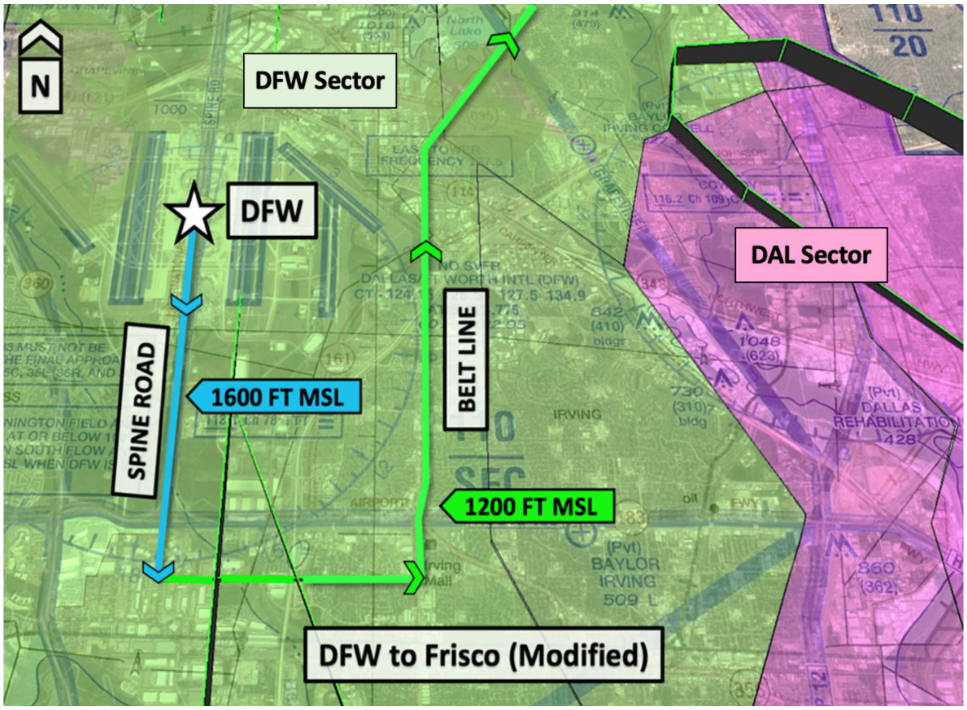

Figure 19. Modified route from DFW to Frisco that minimizes occurrences of sector crossovers.

4.5 Transitioning in and Out of Class B Airspace

Similar to the concept of avoiding going through multiple sectors, UAM routes should, if possible, avoid transitioning in and out of Class B airspace. Any time a UAM or helicopter flight exits and then re-enters Class B airspace requires that the pilot perform the same authorization procedures as the first time they entered the airspace. This would place unnecessary workload on the air traffic controllers coordinating with UAM flights, as well as the pilots themselves. The original helicopter routes for ADS to DFW featured flights departing within Class D airspace and proceeding along Bush. Prior to exiting ADS's Class D airspace and entering Class B, UAM flights would need to contact DFW Tower to receive Class B clearance. Once granted clearance by DFW Tower, flights would proceed along Bush and enter Class B airspace. The Bush route segment eventually meets up with Vista Ridge and uses Spine Road as the entry route segment into DFW, similar to operations arriving from Frisco (see Figure 20).

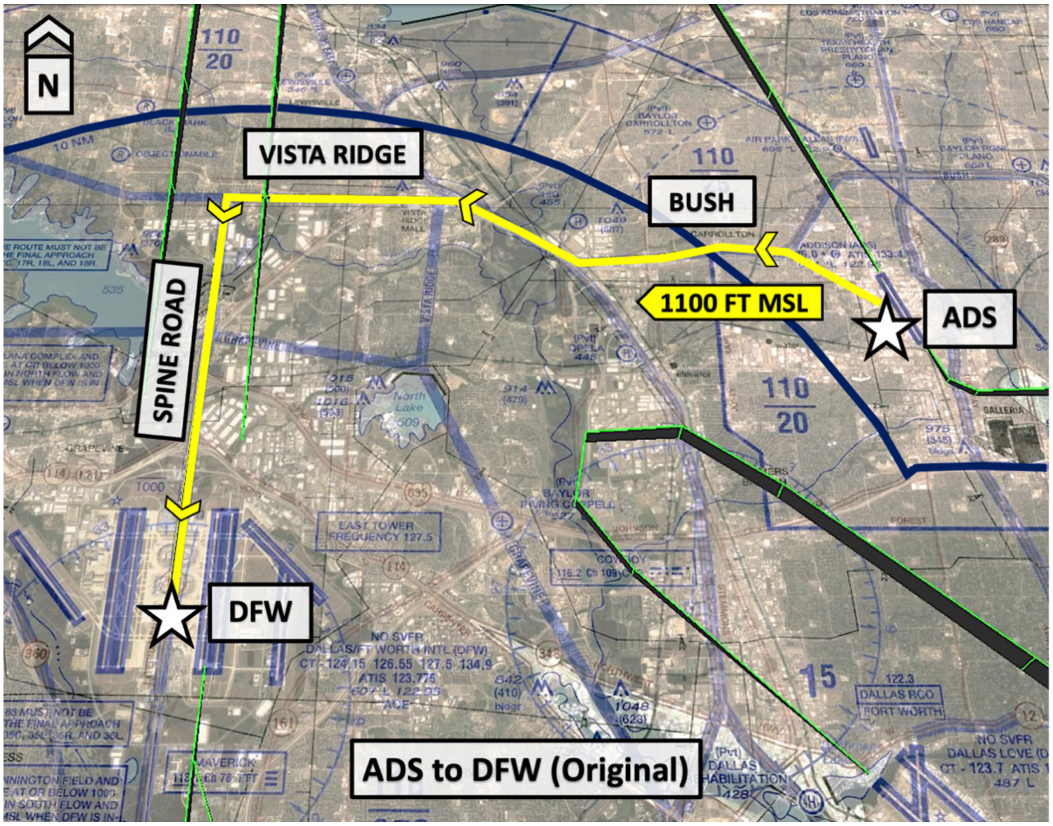

Figure 20. Original route for ADS to DFW that transitions from Class D to Class B airspace with solid dark blue line representing division between the two classes of airspace.

However, to take into account separation issues with arriving traditional flights at DFW, the line up to Spine Road at DFW was pushed back from Vista Ridge in the subsequent modified version of the route (see Figure 21). Now, flights would transition from Class D to Class B and then exit and re-enter Class B airspace while on the approach to line up with Spine Road. The proposed route of ADS to DFW route began at either a Downtown Addison vertiport or Addison airport. The flight would proceed northwest towards Bush.

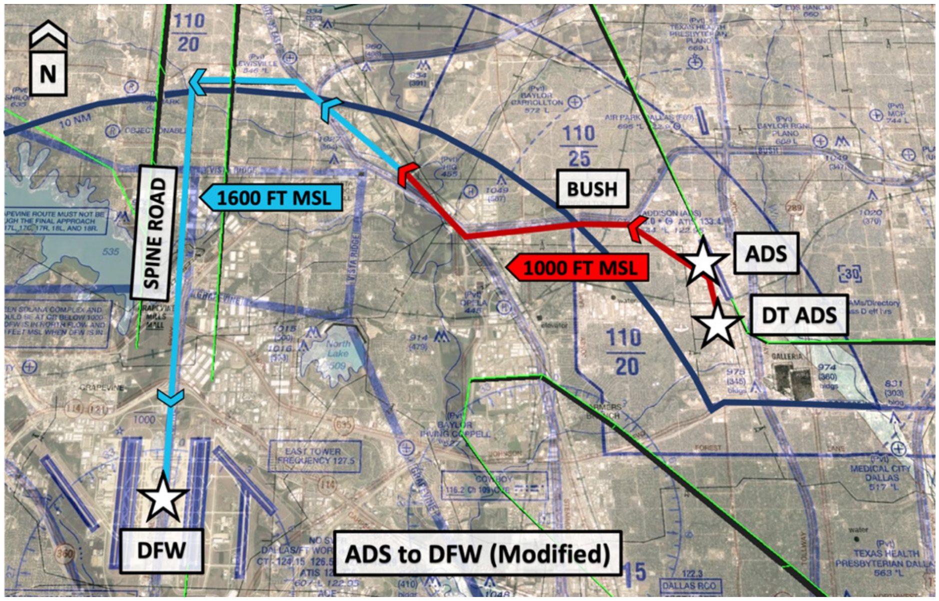

Figure 21. Modified route for ADS to DFW that transitions from Class D to Class B, but exits and re-enters Class B.

The second version of the modified route was developed following SME feedback collected during the HITL. Flights follow the same general path out of Downtown Addison or ADS airport towards Bush at 1,000 ft MSL. Flights would continue at that altitude along I-35 East until the intersection with Vista Ridge, where an altitude of 1,600 ft MSL would be required. Flights would proceed north of Vista Ridge, but well within the Class B airspace border and eventually line up with Spine Road to make the approach into DFW airport (see Figure 22).

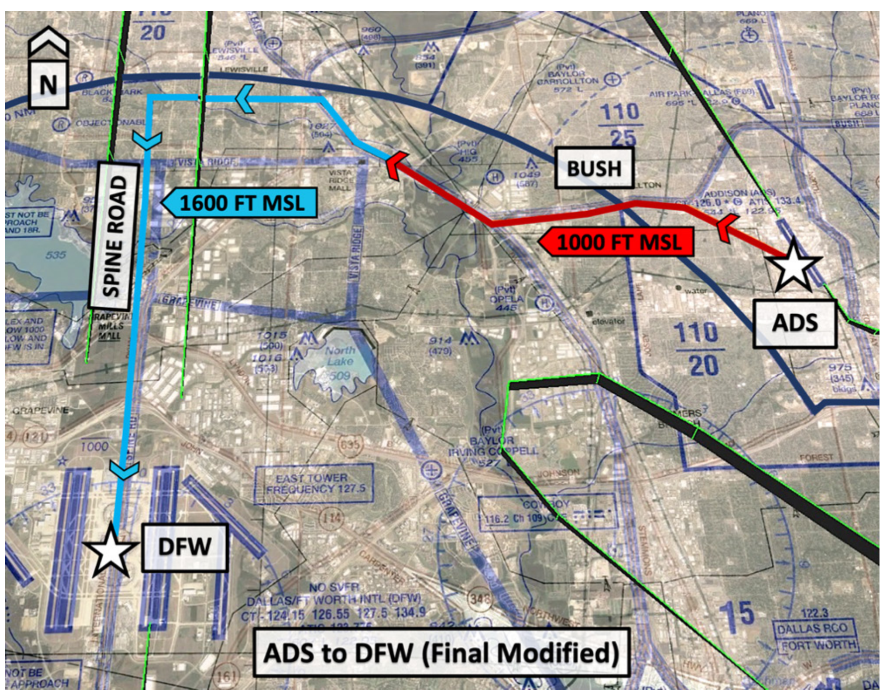

Figure 22. Second version of the modified route for ADS to DFW that stays within Class B airspace.

4.6 Creating Routes Outside of Class B Airspace

When designing routes for UAM operations, if possible, it is best to avoid creating routes that require access to Class B airspace. Accessing Class B airspace is a lengthy process that requires the establishment of two-way communication between the sector controller and aircraft wishing to enter the controlled airspace. By avoiding entry into Class B when able, controller and UAM pilot workload is reduced. One route for DFW that was identified as being usable outside of Class B airspace was Route I-30, which runs just below the boundary for Class B airspace. Route I-30 provides a direct connection between the City of Fort Worth and Downtown Dallas. For current helicopter operations, flights traversing both eastbound and northbound would need to have separation assigned by an air traffic controller, either in the vertical or horizontal dimension. Separation in the horizontal dimension could infringe on neighboring Class B airspace.

The modified version of the route proposed using Route I-30 with two-way traffic separated by altitude. UAM flights departing from Downtown Dallas and proceeding towards Fort Worth would be at an altitude of 1,100 ft MSL. Flights opposite bound, departing from Fort Worth and proceeding towards Downtown Dallas would be at an altitude of 1,600 ft MSL. No other changes would be necessary to avoid the Class B airspace boundary. Figure 23 below depicts the two directional Route I-30 between Fort Worth and Downtown Dallas, as well as its relation to the Class B airspace boundary.

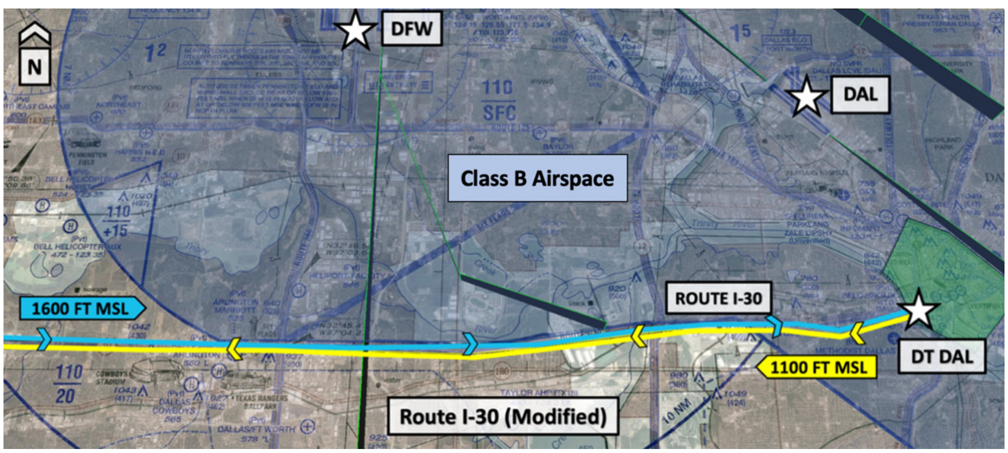

Figure 23. Modified route for Fort Worth to Downtown Dallas with Class B airspace highlighted.

4.7 Designing Two Way Routes with Vertical Separation

Efficiency of UAM routes can be augmented by utilizing two-way traffic in areas where it is safe and makes sense to do so. Separation between streams of traffic should be based on vertical separation (i.e., altitude), rather than just primarily lateral separation. Several routes within the proposed set of routes for DFW utilized this technique. For example, the previous heuristic section mentioned Route I-30 as a two-way traffic route between Fort Worth and Downtown Dallas. UAM flights westbound out of Downtown Dallas and proceeding towards Fort Worth would maintain 1,100 ft MSL, whereas flights eastbound out of Fort Worth and proceeding towards Downtown Dallas would maintain 1,600 ft MSL (see Figure 25). Additionally, the Central Expressway used to connect McKinney Airport (TKI) to Downtown Dallas was another route that could utilize two-way traffic. Altitude separations were similar to those used for Route I-30. Flights departing from TKI and heading southbound on the Central Expressway towards Downtown Dallas had an altitude of 1,600 ft MSL. Conversely, flights from Downtown Dallas and heading northbound on the Central Expressway towards TKI had an altitude of 1,100 ft MSL (see Figure 24).

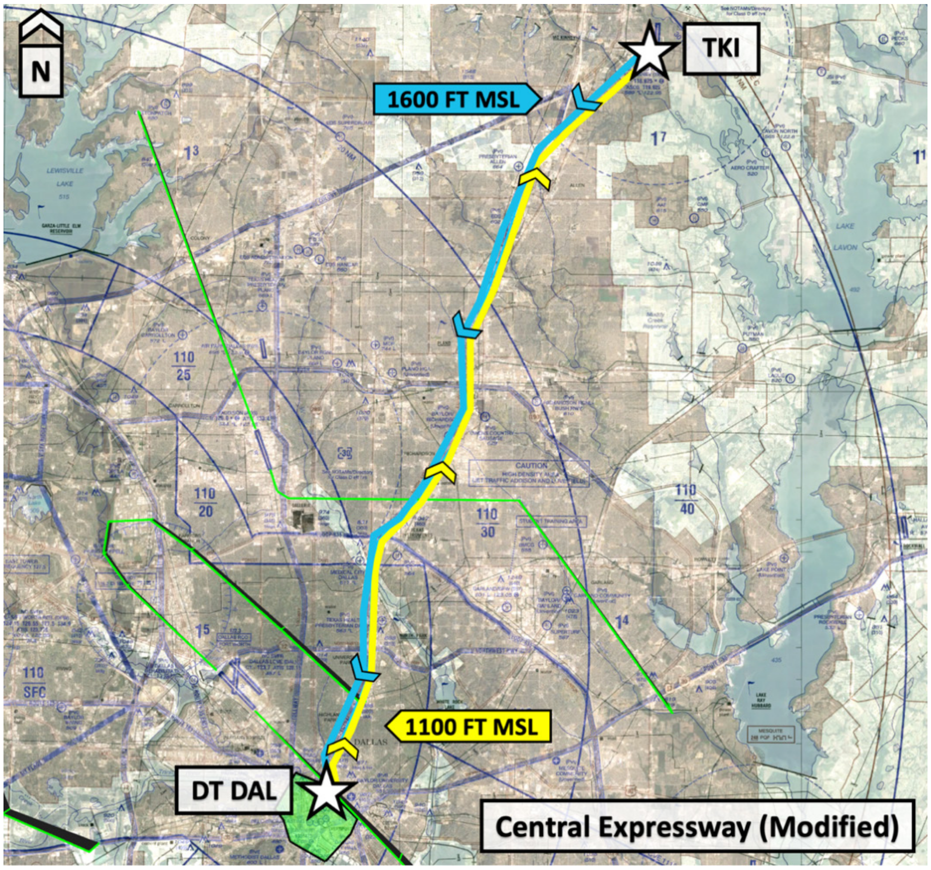

Figure 24. Modified version of Central Expressway used for McKinney to Downtown Dallas and vice versa.

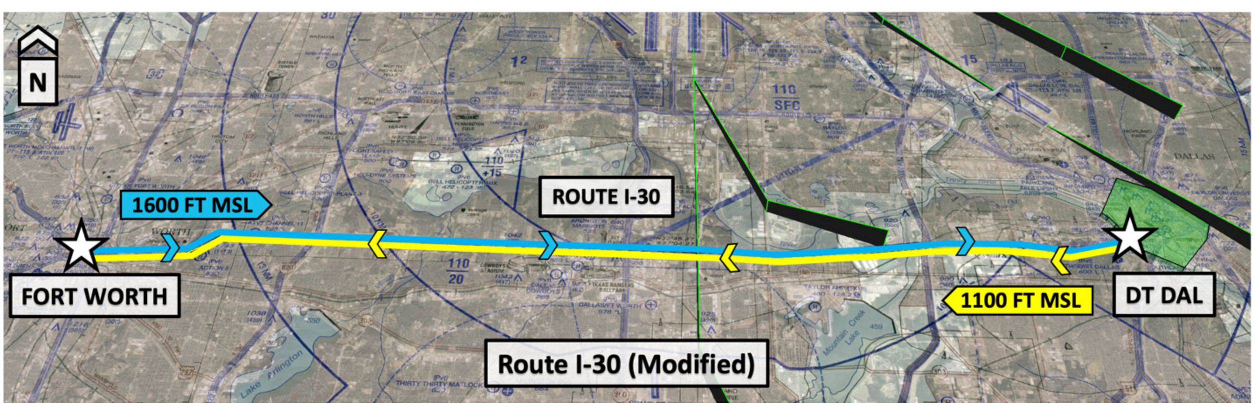

Figure 25. Modified version of I-30 used for Fort Worth to Downtown Dallas

4.8 Minimizing Route Length

One of the key limiting factors to future UAM operations is potentially limited energy reserves for electric vehicles. Most UAM ConOps imagine the usage of eVTOL vehicles that would require substantial battery life in order to operate on longer routes and maintain a sufficient, final fuel or energy reserve in case of any contingency events that would require the vehicle to stay airborne. Thus, it is important to consider minimizing route length in order to minimize energy needed to reach the destination. Additionally, prioritizing minimized route lengths will lead to shorter trip times that will benefit UAM operators and passengers. The original helicopter route for DFW to Frisco was 41.9 miles (i.e., 36.4 nmi). Flights would depart from a vertiport located at DFW and proceed southbound on Spine Road to the intersection with Route 183. At the intersection with Route 183, flights would turn left and proceed eastbound on Route 183 towards the Grapevine. Flights would follow the Grapevine towards Route I-35 East and then exit Class B airspace (see Figure 26).

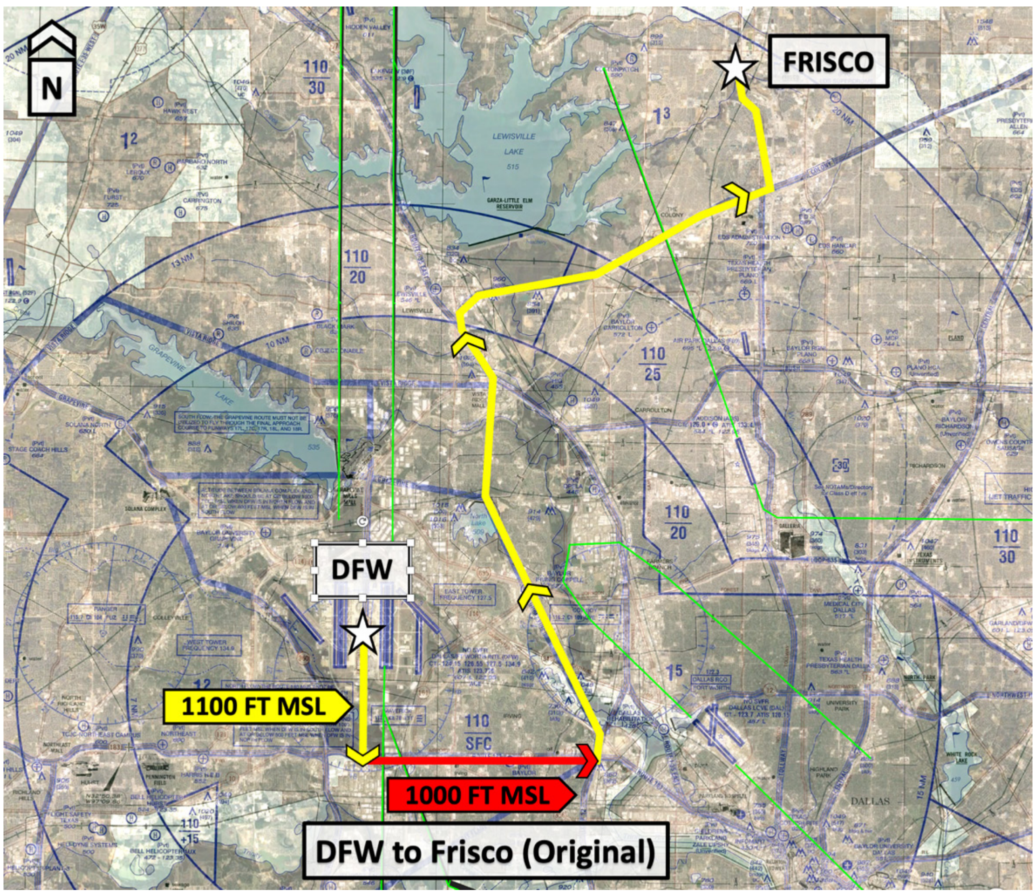

Figure 26. Current helicopter route for DFW to Frisco.

Modifications made to this route specifically addressed minimizing route length by utilizing the North Belt Line Road instead of following the entire segment of Route 183 and the Grapevine. By cutting to the North Belt Line Road from Spine Road, the overall length of the modified route is instead roughly 30 miles (i.e., 26.5 nmi). This change ultimately reduced the length of the DFW to Frisco route by nearly 11.9 miles (i.e., roughly 9 nmi). See Figure 27.

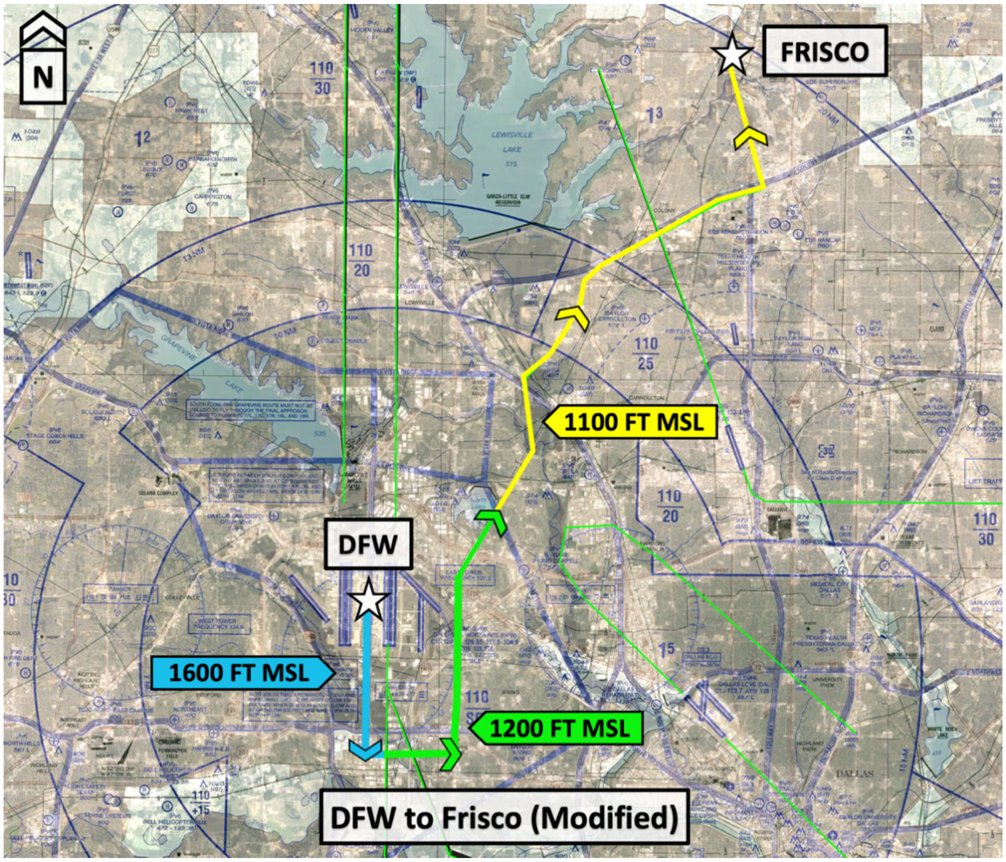

Figure 27. Modified route for DFW to Frisco.

4.9 Commonly Placed Temporary Flight Restrictions (TFRs)

When designing airspace for UAM operations, it is important to consider avoiding commonly placed TFRs. For current published helicopter routes around Addison, there is no routing that allows for direct access to the airport or Downtown Addison. However, published routes for the North Dallas Tollway, Bush Turnpike, and Loop 635 cross near these locations. Flights could follow the North Dallas Tollway coming from the south of the airport and Downtown Addison. However, multiple issues exist with usage of the North Dallas Tollway. In 2009, a permanent TFR was published under a Notice to Airmen (NOTAM) (i.e., FDC 9/2934) for an area around the intersection of the North Dallas Tollway and Loop 635 to allow for regularly scheduled, very important personnel movement (see Figure 28). The radius of the TFR is about 1 nm and covers from surface level to 2,100 ft MSL [13]. The TFR would most likely cause the North Dallas Tollway to be completely unusable or require complex rerouting and handling by air traffic control around the TFR in near-term UAM operations.

Figure 28. NOTAM sectional chart for permanent TFR shown in red circle along North Dallas Tollway.

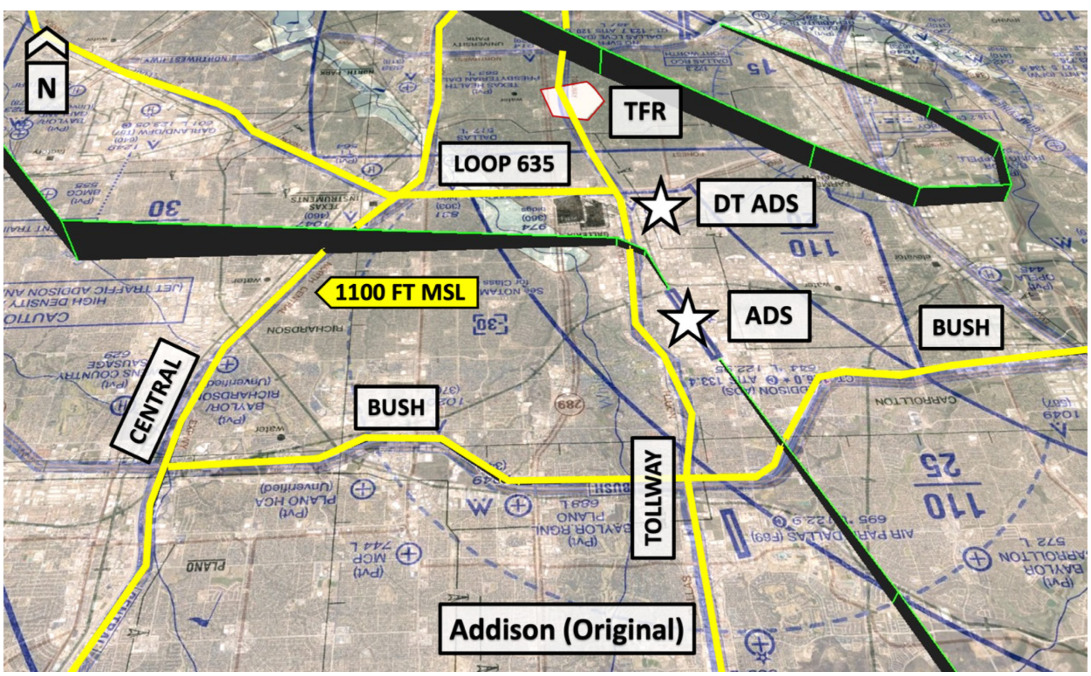

Figure 29. Current helicopter routes around ADS and Downtown Addison.

During the cognitive walkthrough, SMEs voiced similar concerns regarding the feasibility of being able to use the Tollway for near-term UAM operations. SMEs suggested that, instead, UAM flights should primarily utilize the Central Expressway located to the east of the Tollway to traverse between the northern and southern parts of the DFW metropolitan area. The Central Expressway could also utilize two-way, altitude-separated traffic to support both northbound and southbound UAM traffic. Another suggestion that was independently made by SMEs during the cognitive walkthrough was to add a route crossing ADS airport midfield from the Central Expressway. This would help to reduce the distance flown for flights between ADS airport and the Central Expressway. The modified version of the route network surrounding ADS airport and Downtown Addison removed the North Dallas Tollway and established two-way altitude separated routes along the Central Expressway to connect McKinney and Downtown Dallas. The suggestion for the mid-field route at ADS airport was also implemented with an altitude of 1,100 ft MSL to help connect flights from Addison to the Central Expressway (see Figure 30).

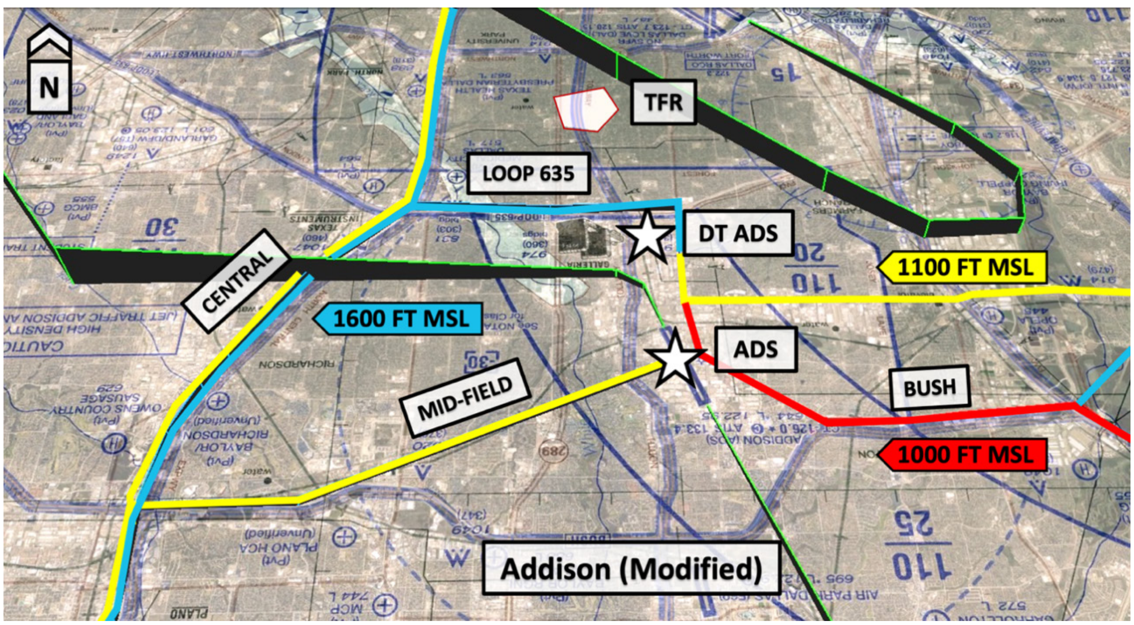

Figure 30. Modified routes surrounding ADS and Downtown ADS.

4.10 Creating Non-movement Areas or UNICOM Areas

In certain cases, when designing UAM routes, the establishment of a non-movement area or UNICOM area would help significantly reduce communication load of the FAA controller. A UNICOM area is a nongovernment or non-FAA air/ground communication station which may provide airport information to pilots thus delegating the responsibility of landing in these zones to UAM and vertiport operators and relieving the controllers from such responsibilities. A UNICOM area is like a ramp area on the surface of the airport, which is managed by airlines and not by FAA controllers. A UNICOM area would be treated similar to the ramp area and would likely be managed by a third party that would handle the traffic in that area and use Common Traffic Advisory Frequency (CTAF) to provide such information to the flights. For example, current helicopter routes provide multiple pathways to Downtown Dallas (as seen in Figure 30). The Tollway and part of the Central Expressway allow for flights coming from the northern part of the airspace (e.g., Frisco, Addison, McKinney). Thornton would cover flights coming from the eastern part of the airspace, whereas Route 183 and Route I-30 would provide routing from the western part of the airspace (e.g., DFW, Six Flags). However, flights arriving and departing for Downtown Dallas would need to be in communication with Dallas Tower. Flights departing from vertiports within Downtown Dallas would need to contact DAL Helo position prior to departure for a clearance. Additionally, flights inbound would need to be handled by Dallas Tower until landing at the destination vertiport. This would potentially cause significant workload on the DAL Helo controller who would be most likely responsible for these communications and handling of UAM flights.

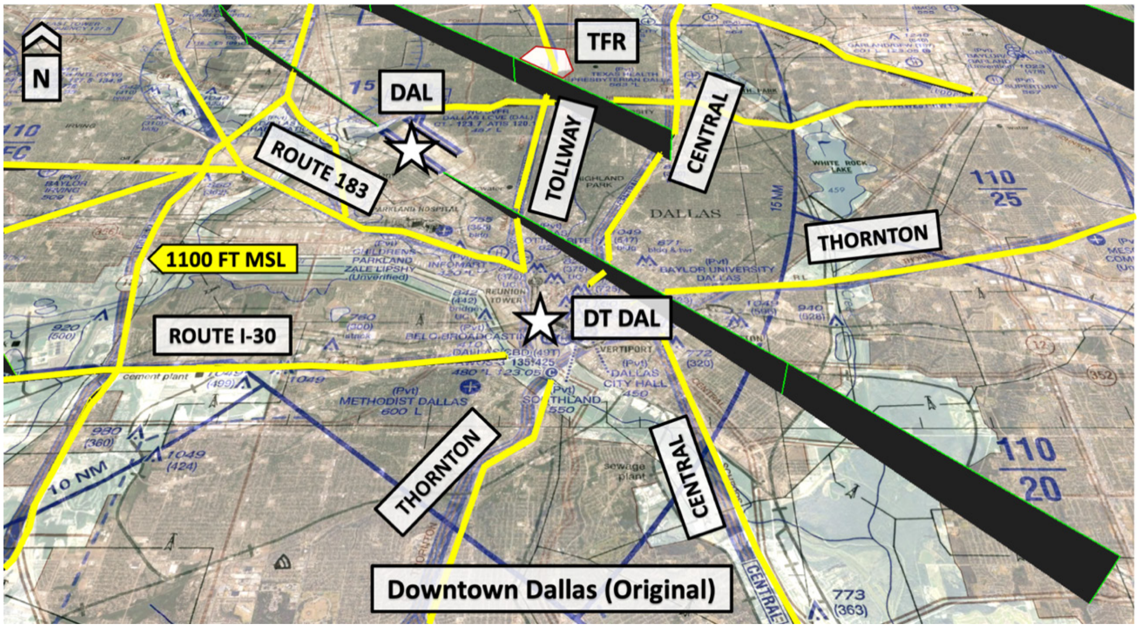

Figure 31. Original helicopter routes surrounding Downtown Dallas.

As a result of identifying the aforementioned communication restraints, a UNICOM area was proposed for Downtown Dallas. When departing from Downtown Dallas, UAM pilots would call and check in with the DAL Helo controller upon reaching a transition point at the edge of the UNICOM area. This would mitigate the need for calling upon departure from the vertiport location. These transition points will allow UAM flights to proceed to different routes. Additionally, any movement of vehicles inside the UNICOM area would be managed by the UAM operator instead of the DAL Helo controller.

During the initial cognitive walkthrough, SMEs agreed that the establishment of a non-movement area or UNICOM area would help significantly reduce communication load on DAL Tower and allow UAM flights to move within the area without coordination with DAL Tower. Furthermore, SMEs suggested the removal of the Tollway as an entry route into the UNICOM area due to the active TFR present near the proposed UNICOM area. Thus, Central Expressway, Thornton, Route 183 (original), Trinity River (modified Route 183), and Route I-30 would be the routes that would intersect with the Downtown Dallas UNICOM area (as shown in Figure 32).

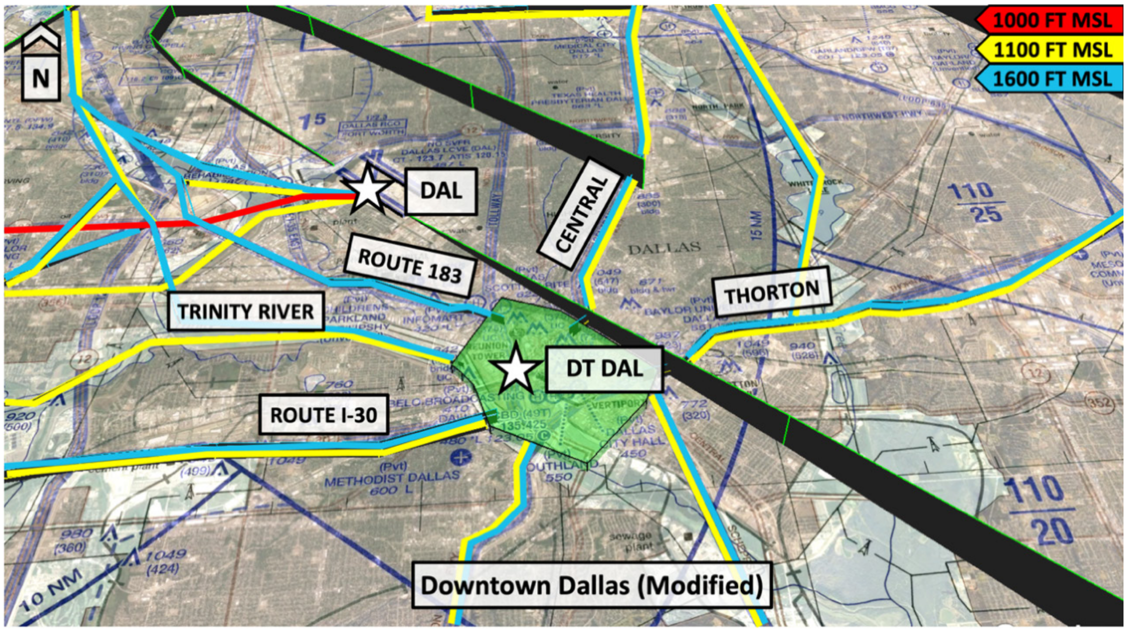

Figure 32. Modified routes surrounding Downtown Dallas UNICOM area.

5. Conclusion

As part of an investigation into near-term UAM operations, a UAM route network based on the greater Dallas-Fort Worth area's current helicopter route network was assessed for operational constraints and feasibility of integration through a cognitive walkthrough and HITL study. The resulting activities unearthed a number of lessons learned for adapting helicopters routes for usage by near-term UAM flights.

The development of any UAM route network should examine how UAM vehicles will operate in relation to pre-existing entities and operations. This includes taking into account the proximity of proposed UAM routes to surrounding airports within a given airspace (e.g., location in relation to the approach and departure paths of traditional traffic) and the configuration of surrounding airports and how operations may change based upon the traffic flow decided for that operational day (e.g., south versus north flow at DFW). UAM routes should minimize workload impacts for air traffic controllers, such as routes from traversing through multiple airspace sectors or classes of airspace that would require excessive coordination between the UAM operator and air traffic control facilities.

Creation of UNICOM areas would also reduce workload on air traffic control by delegating the responsibility of landing in these zones to UAM and vertiport operators. Placing routes outside of Class B airspace would also reduce the amount of coordination required to normally enter and exit controlled airspaces. Additionally, considerations such as using two-way, altitude-separated routes and minimizing route length will help make UAM operations more efficient and less intrusive to traditional traffic. Route networks should also steer clear of well-known airspace constraints, such as TFRs and special use airspaces.

Possible routes that will be feasible for usage in the near-term within the greater Dallas-Fort Worth metropolitan area include Route I-30 and Central Expressway. Both routes are located outside of Class B airspace and can be potentially utilized as two-way altitude separated routes. These routes can be utilized to access Downtown Dallas from either the north via the Central Expressway or from the east via Route I-30. It is possible that access to Downtown Dallas can be made from DFW via the route that was defined for these analyses, which is located south of the I-183. Additionally, the usage of the Belt Line or an equivalent route would allow for north and south movement inside Class B airspace. Some of the other routes identified in this paper, such as those using Spine Road to either depart or arrive at DFW from the north or south, will require further analysis to better understand the full extent of how potential UAM flights will interact with traditional traffic and the resulting safety and workload impacts for air traffic controllers.

Most of these heuristics that were developed for Dallas area can be generalized to other airports. DFW and DAL are unique in the sense that the Class B airspace extends through the surface whereas the challenges in other airports, example, Los Angeles (LA) basin may be different. The LA Basin also needs to use most of the heuristics identified in this document but would have the additional challenge of terrain that would need to be considered when designing UAM routes.

Future development will need to consider increasing demand and higher UAM traffic densities. This will likely require adoption of routes no longer based on helicopter routes for mid-term and far-term usage, aligning with goals outlined for more mature UMLs. These operations will instead borrow concepts from Unmanned Aircraft Systems Traffic Management, or UTM, a proposed traffic management framework where small UAS submit airspace plans and associated volumes and receive approval through an entity outside of traditional air traffic management known as a UAS Service Supplier (USS) [13, 14]. While the local Airspace Navigation Service Provider, or ANSP, will have the ultimate authority, the usage of a USS, or Provider of Services to UAM (PSU) as it has been proposed, would alleviate strain for traditional air traffic management. However, the heuristics identified here will be relevant when identifying areas of airspace that will be available to UAM flights for the development of corridors as proposed by the FAA Nextgen ConOps v1.0 [5], particularly in the cases where there will be a need to have altitude-separated, two-way traffic to accommodate a larger density of flights in UAM-specific corridors. Additionally, corridors may also need to be implemented in areas that avoid, or are deconflicted from, the approach and departure paths of traditional traffic, as well as highly populated areas to prevent noise nuisances to the surrounding communities that they are serving. Future research conducted will examine operations for entering and exiting corridors and how deviations might be coordinated with the PSU in contingency type events.

Acronyms

ADS	Addison Airport
AGL	Above Ground Level
ANSP	Airspace Navigation Service Provider
ConOps	Concept of Operations
CTAF	Common Traffic Advisory Frequency
DAL	Dallas Love Field
DFW	Dallas Fort Worth International Airport
eVOTL	Electric Vertical Takeoff and Landing
HITL	Human in the loop
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions
LOA	Letter of Agreement
MSL	Mean Sea Level
PSU	Provider of Services to UAM
SMEs	Subject Matter Experts
TFR	Temporary Flight Restriction
UAM	Urban Air Mobility

UAS	Unmanned Aircraft System
UNICOM	Universal Communication
UML	UAM Maturity Level
USS	UAS Service Supplier
UTM	UAS Traffic Management
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions

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