Investigation of Communications Involved in Near-term UAM Operations

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Abstract—**The present research explored whether the implementation of a letter of agreement (LOA), or pre-established written terms of engagement, would reduce controller communication associated workload in a HITL study simulating a near-term UAM infrastructure with varying traffic levels. Current helicopter routes, including modified versions, and communication procedures were outlined in the LOA. Time spent communicating was reduced under both conditions featuring a LOA, for current and modified routes, compared to present day procedures without a LOA. Results suggest that utilizing current-day helicopter routes and implementing a LOA may prove beneficial for near-term low-density and low-tempo UAM operations.**

Keywords—urban air mobility, air traffic control, communications, workload

I. Introduction

Proposed Urban Air Mobility (UAM) operations will provide advanced air passenger transportation for populous metropolitan communities, offering an alternative method of avoiding traffic congestion along a target consumers' commutes. Target communities include locations such as San Francisco, Los Angeles, Detroit and New York City [1]. Several concept of operations (CONOPS) generated by industry partners and government agencies specify UAM traffic will likely operate with Electric Vertical Takeoff and Landing Vehicles (eVTOLs) in varied airspaces, including altitudes within Classes B, C, and D possibly under visual flight rules (VFR). UAM flights will depart and arrive at city destinations via vertiports (e.g., operational pads similar in design to already existing helipads). To successfully integrate with the present national airspace system (NAS), flight scheduling, flight planning, air traffic coordination procedures, and vehicle performance requirements must be thoroughly investigated for technical or design barriers. Currently, NASA is working with industry partners and academia to generate solutions and guidelines for near-term UAM operations. Presently identified key constraints for a future UAM infrastructure suggest that it should: (1) not require additional ATC infrastructure, (2) not increase current workload levels for air traffic controllers, (3) not impose operational restrictions upon traditional airspace users (e.g., commercial IFR traffic), (4) not violate safety thresholds and requirements, (5) have operational scalability as a priority, and (6) be accommodating in areas that need it, while providing clear structure [2].

Arguably, one of the most significant barriers to the successful integration of UAM into the current NAS is the predicted, additional strain on air traffic controller workload, particularly strain related to communication levels. Within a near-term UAM system, controllers most likely to be in contact with UAM aircraft will be at the tower or terminal level. These controllers are already burdened with increasing traffic loads in the present day NAS. For example, Class B airspace extends from surface level to at least 10,000 feet mean sea level (MSL) and encompasses the vast majority of the NAS's busiest air traffic facilities and airports. Current procedures for receiving Class B clearance for a VFR flight is a multi-step process involving voice communication and radar identification. A VFR pilot must first contact a local tower controller prior to entering Class B airspace and provide his or her aircraft's callsign, position, specific route, and most recent Automatic Terminal Information Services (ATIS) information. Following contact from the VFR pilot, the controller provides Class B clearance; this is accomplished by identifying the calling aircraft on his or her radar scope and providing further route instructions. Additionally, a unique beacon code must be assigned for the VFR flight to squawk. In a UAM infrastructure utilizing Class B airspace, controllers would need to perform this clearance task for each individual UAM flight. This task would need to be completed alongside handling tasks of departing UAM flights, as well as typical handling tasks with traditional instrument flight rules (IFR) and VFR aircraft. With mounting pressure for future evolution into mature high-tempo, high-density UAM operations, communication-associated workload for controllers poses a significant risk to safety and efficiency of the proposed UAM infrastructure [3, 4].

Given these constraints, the implementation of a letter of agreement (LOA) between operating UAM company parties and air traffic control facilities may prove beneficial to reducing communication-associated workload for both air traffic controllers and UAM pilots in the near-term. A LOA would outline regulatory conditions and delegate individual responsibilities agreed upon by all signatories for UAM operations within a given airspace. The LOA's purpose would be to provide reduction in verbal communication requirements by detailing specific, pre-authorized UAM routes and associated restrictions. Each UAM route within a given operation zone would have a unique associated route name or code. For every unique UAM company in operation, a pre-assigned beacon code would be utilized upon entering class B airspace; this negates the requirement for one that is randomly generated by a controller and verbally assigned. Such operational measures could potentially help to cut back on general controller workload and communication-associated workload.

The present human-in-the-loop (HITL) study examined whether a near-term solution for UAM operations within the Dallas Fort-Worth area could alleviate communication-associated workload for tower and local controllers by supplementing present day helicopter routes with communication and procedural requirements within a LOA.

II. Methods

A. Participants

Controller participants served as either the Dallas Fort-Worth Local East-3 Tower position (DFW LE-3), DFW LE-1 Tower position, or DFW West Tower position at DFW International Airport (DFW). For Dallas Love Field Airport (DAL), controllers served as the helicopter position (Helo) or the DAL Local Tower position. For Addison Airport (ADS), controllers served as the ADS Local Tower position. Controllers arranged for data collection at the DFW LE-3 position swapped between data runs to the DFW LE-1 position. DAL Helo controllers switched to the DAL Local position, while ADS Local controllers swapped to the DFW West position. Controllers experienced all conditions twice as either the primary position or an associated secondary position. All participants were retired air traffic controllers. All controllers had previous experience with their assigned position except for those controllers stationed at ADS or DFW West, who had prior experience with Northern California Terminal Radar Control (TRACON). Researcher confederates acted as the controllers for TRACON D-10, which did not require voice communication with simulated UAM traffic.

B. Experimental Matrix and Procedures

Each trial was 40 minutes long. Each trial featured one of three UAM traffic levels (i.e., low, moderate, and high) based upon a departure time frame. Traffic levels were presented in randomized order for each experimental block. One trial was run without UAM traffic and used only traditional aircraft to capture a baseline. Background traffic (i.e., traditional IFR and VFR flights) based on historical sector data remained consistent across UAM traffic level manipulations. Three conditions were tested including *Baseline without LOA, Current Routes with LOA,* and *Modified Routes with LOA (*see Table 1). Elements of the background traffic used in all scenarios are shown in Table 2. Characteristics of UAM traffic levels are outlined in Table 3.

TABLE I. Experimental Matrix

Experimental Blocks	**UAM Traffic Levels**		
	Low (1)	***Moderate (2)***	***High (3)***
Baseline without LOA (C)	C1	C2	C3
Current Routes with LOA (CL)	CL1	CL2	CL3
Modified Routes with LOA (M)	M1	M2	M3

TABLE II. Background Traffic

Flight Type	**Airport**		
	DFW	***DAL***	***ADS***
Total IFR Flights – Arriving	54	16	6
Total IFR Flights – Departing	50	20	1
Total VFR Flights – Arriving & Departing	0	1	11
Grand Total of Flights	104	36	18

TABLE III. UAM Traffic Level Characteristics

Characteristic	**UAM Traffic Levels**		
	Low	***Moderate***	***High***
En Route Temporal Spacing in Seconds (s)	90 s	60 s	45 s
En Route Spacing in Miles (mi)	3.75 mi	2.50 mi	1.86 mi
Total Number of Flights	115	167	225

One run without UAM traffic was conducted before the onset of the experimental conditions with UAM traffic integrated. This run featured traditional IFR and VFR flights that only followed current-day procedures and communications. Similar procedures were followed with the introduction of UAM traffic in the *Baseline without LOA* condition. It assumed no LOA between UAM companies and the Dallas control facilities. All UAM routes were based upon present day, published helicopter routes. Controllers were instructed to assign altitudes as needed to provide safe separation and deconflict UAM flights. Controllers were instructed to make traffic calls or point outs to both traditional and UAM traffic, as well as other air traffic facilities when necessary. Departing UAM pilots were instructed to call in 30 seconds prior to departure from vertiport with callsign and indication of readiness for takeoff. To receive clearance into Class B airspace, UAM pilots called ahead of entering, giving the approaching fix, describing intended route, and providing current ATIS information. If a controller was not able to locate an aircraft, an identify (or "ident") functionality on transponder was available for pilots to initiate, shown as two slanted bars near the aircraft on the controller's radar scope. UAM arrivals were instructed to call in and indicate the route portion, as well as intention to land at vertiport. Controllers handed off UAM flights prior to exiting his or her sector with the appropriate tower for contact with associated frequency. The downstream controller had the option to deny hand-offs from surrounding controllers. UAM aircraft exiting Class B airspace had cancellation of radar service by an associated controller and told to squawk the beacon code for VFR. For the Class D airspace surrounding ADS, UAM pilots made radio contact for clearance at least 10 nautical miles away from the airport. Traffic transitioning between DAL and ADS was handed-off between facilities. A frequency change was required by a controller at that time. DAL arrivals were instructed to follow procedures for entering Class B airspace, whereas the DAL tower was required to terminate radar service for aircraft entering ADS airspace upon handoff.

The *Current Routes with LOA* introduced procedures meant to reduce verbiage, define routes precisely, and provide greater separation between the routes. The LOA outlined applicable definitions, responsibilities, departure procedures, approaching and exiting procedures (for Class B and D airspaces), sector transition waypoints, and route information for all UAM aircraft. Each UAM route was also assigned a route name to minimize the earlier practice of using descriptive verbiage of intended flight route. Controllers did not need to assign a unique beacon code in these conditions, as these were pre-assigned based upon the signatory operators. Additionally, automatic frequency changes were assumed when exiting Class B airspace. An ATIS broadcast featuring advisories for heavy UAM traffic within the Dallas Fort-Worth area, specifically along a congested route leg known as Spine Road, was assumed. This was implemented in the hopes of alleviating traffic calls to traditional aircraft. Furthermore, point outs between air traffic facilities initiated by DFW were no longer needed to be verbally addressed as they were outlined in the LOA.

Finally, the *Modified Routes with LOA* condition featured the same assumptions as the *Current Routes with LOA* condition, but implemented changes to UAM routes for increasing separation from arriving or departing traditional airport traffic, maximizing route efficiency, and avoiding any typical Temporary Flight Restrictions (TFRs) within the airspace. Examples of communication procedure differences between conditions without LOA versus those with LOA are outlined in Table 4 and 5.

TABLE IV. CLASS B CLEARANCE COMMUNICATION COMPARISON

	UAM Pilot	***Controller***
Without LOA	"DFW Tower, UAM422, approaching [*waypoint along route*], request Bravo clearance via Highway 121, Route I-35 East, Vista Ridge, and Spine Road with information Whiskey."	"UAM422, DFW Tower, cleared via Dallas Three."
With LOA	"DFW Tower, UAM422, approaching CYOTE via Dallas Three."	"UAM422, DFW Tower, cleared to enter class Bravo. Squawk 4043. [*Additional instructions (e.g., descend for traffic separation)*]."

TABLE V. DEPARTURE CLEARANCE COMMUNICATION COMPARISON

	UAM Pilot	***Controller***
Without LOA	"DFW Tower, UAM422, ready for takeoff."	"UAM422, DFW Tower, wind calm, departure from vertiport will be at your own risk."
With LOA	"DFW, UAM422, ready for takeoff, Love One."	"UAM422, DFW Tower, cleared via Love One."

C. Assumptions for UAM Aircraft and Airspace Design

For the purposes of the study, UAM aircraft were assumed to be EVOTLs that had performance characteristics similar to a Cessna 172 Skyhawk. All UAM aircraft flew under VFR and had a cruise speed of 130 knots. UAM aircraft were only in contact with the primary controller positions (i.e., DFW LE-3, DAL Helo, and ADS Local) and had no contact with the airspace's TRACON controllers for the duration of the study. Each UAM aircraft had an assigned beacon code at all times. A VFR beacon code was used outside of Class B airspace and unique codes (i.e., controller generated with no LOA or preassigned with LOA) were used upon entering the airspace. Weather conditions were assumed to be clear with calm winds. All UAM departing and arriving vertiports featured unique names that controllers were trained on.

UAM routes used for the simulation were based upon current helicopter routes published for the general Dallas Fort-Worth area and applicable in south flow only. The Multi Aircraft Control Simulator (MACS) simulated the Dallas, Texas airspace, including all overflights, airport arrival streams and departures, and UAM routes. Each controller station emulated the Standard Terminal Airspace System (STARS) and was equipped with a terminal keypad, scratchpad, and trackball. UAM routes utilized portions of Spine Road, Vista Ridge, Grapevine, Route 183, I-30, Highway 121, Bush Highway, North Dallas Tollway, and Central Expressway. For the *Baseline without LOA* condition, certain portions of flight routes were assumed to be bi-directional (i.e., Highway 121, North Dallas Tollway, Central Expressway and I-30) and required altitude separation issued by controllers (see Fig 1). Once a LOA was introduced, the *Current Routes with LOA* condition featured the same routes, but with specific altitude separations assumed for all bi-directional UAM routes. For example, the Central Expressway utilized 500 ft separation with southbound traffic traveling at 1,600 ft and northbound traffic traveling at 1,100 ft MSL.

Routes were modified for the *Modified Routes with LOA* condition. This was done to test whether changes to altitude and route path facilitated better separation between UAM traffic and conventional commercial departures and arrivals, as well as maximizing flight efficiency. Changes to the original routes were based upon feedback gathered with subject-matter experts, or SMEs, in a cognitive walkthrough of the proposed UAM routes and procedures. For example, flights along the North Dallas Tollway included in the *Baseline without LOA* and *Current Routes with LOA* conditions, were removed for the *Modified Routes with LOA* condition due to potential conflicts arising between UAM traffic and arriving or departing traffic into KADS and KDAL (see Fig 2).

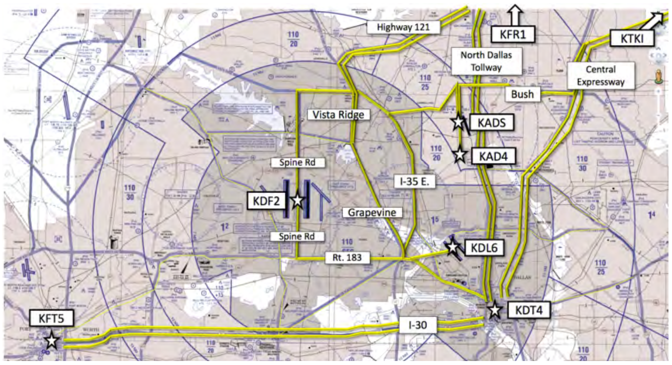

Fig 1. Example map of the UAM routes utilized for the *Baseline without LOA* condition.

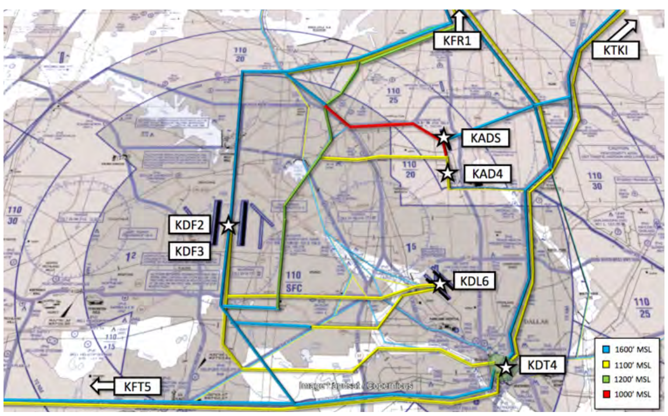

Fig 2. Example map of the UAM routes utilized for the *Modified Routes with LOA condition*.

D. Data Collection Procedures

On the first day of the simulation, participants received an initial project briefing meant to familiarize them with the research topic. Following the project briefing, participants were briefed on the procedures for the *Baseline without LOA* condition. The procedure briefing outlined general guidelines for each controller position, expected communication behaviors with UAM aircraft, and planned UAM routes. Participants were then given time to familiarize themselves with the system through a training run. Once participants felt they were proficient enough, one trial was run with no UAM aircraft and only traditional IFR or VFR flights. Controllers then experienced all UAM conditions in order of the *Baseline*, *Current Routes with LOA*, and *Modified Routes with LOA*. Controller participants saw every traffic level at least twice in random order; once as the primary data collection position or the secondary ghost station position. Between conditions, controllers received briefings that covered guidelines on UAM routes and interactions for the upcoming condition.

During each trial, all voice communications were recorded (i.e., pilot to controller, controller to pilot, and controller to controller). Following the end of the simulation, total elapsed time in seconds for each run was calculated along with the total time of communications in seconds. Percentage of time spent communicating was computed for each participant's run by dividing total time of communications by total elapsed time and converting the proportion into a percentage.

Following each trial, participants filled out a brief electronic questionnaire asking about their experience with the previous condition and associated traffic level. At the end of each block, participants answered questions regarding their overall experience. Participants could give additional final feedback at the end of the study during the post-simulation questionnaire and the final, verbal debriefing session.

III. Results

The analyses for the present paper will focus on the audio metric collected, as well as subjective feedback from controllers. Significance testing will not be discussed due to smaller sample size for each individual controller position (n = 2). Results will be discussed using descriptive statistics and associated trends. Findings regarding controller online workload ratings and UAM flight metrics (e.g., lateral separation and count of UAM handled) are discussed in [5, 6].

A. Audio Metric

A 40-minute run was completed with traditional IFR and VFR air traffic only. Since this run was not duplicated, data was only collected for one controller participant per position (n = 3). The controller placed at the DAL Helo position, who primarily managed VFR helicopter flights, spent approximately 4.69% of the run communicating with IFR pilots or other controllers. The DFW LE-3 controller, who was responsible for arrivals on runway 17L, had a slightly higher amount of communication, with 7.33% of the run spent communicating. Finally, the ADS Local controller had a significantly higher amount of communication with 25.42%. The ADS Local controller position's increased communication is likely due to this position requiring management of all VFRs at a Class D airport. This is done without an additional controller position in the real operational environment for ADS.

Following the introduction of UAM traffic, all controller communication levels significantly increased. Average percentage of time spent communicating was highest within the *Baseline* condition (M = 54.74%, SD = 17.93%), with controllers spending almost over half the elapsed data collection run time communicating. Both the conditions featuring a LOA (i.e., *Current* and *Modified Routes*) had lower percentages of communication than the *Baseline* condition. The *Current Routes with LOA* condition had a slightly lower average percentage of communication (M = 43.59%, SD =

8.92%) than the *Modified Routes with LOA* condition (*M* = 46.29%, *SD* = 14.41%; see Fig 3).

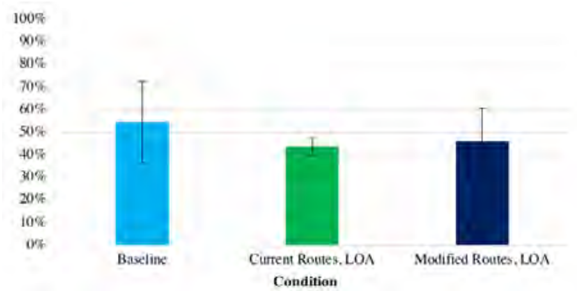

Fig 3. Average percentage of time spent communicating collapsed by condition across all controller positions.

When examining percentage of time spent communicating by just UAM traffic levels alone, an expected increase is seen going from the low traffic level (*M* = 40.76%, *SD* = 9.90%) to moderate (*M* = 48.66%, *SD* = 14.26%), and high levels **(***M* = 55.19%, *SD* = 16.86%). When collapsed across all conditions and traffic levels, DFW LE-3 controllers had the highest average percentage of time spent communicating (*M* = 59.20%, *SD* = 4.62%) compared to DAL Helo (*M* = 54.15%, *SD* = 3.01%) and ADS Local controllers (*M* = 31.26%, *SD* = 1.44%).

When DFW LE-3 controllers experienced low UAM traffic, the *Baseline* condition had nearly double the average percentage of communication (*M* = 61.28%, *SD* = 8.04%) compared to averages found for the *Current Routes with LOA* condition (*M* = 35.57%, *SD* = 2%). The *Modified Routes with LOA* had a slightly higher average (*M* = 43.98%, *SD* = 0.42%) than the average for the *Current Routes with LOA* condition, but still had nearly 20% less than that for the *Baseline* condition under low traffic. Moderate traffic produced the highest average percentage of communication within the *Baseline* condition (*M* = 68.16%, *SD* = 6.32%) followed by the *Modified Routes with LOA* condition (*M* = 58.09%, *SD* = 5.21%). The lowest average amount of communication occurred within the *Current Routes with LOA* condition (*M* = 56.27%, *SD* = 9.64%). The decrease in average amount of communication-associated with the moderate traffic was pronounced as compared to the one observed with low traffic; this only roughly had a 10% difference between the *Baseline* and either LOA conditions featuring the *Current* or *Modified with LOA* routes. With high traffic, the *Baseline* condition once again had a higher average percentage of communication (*M* = 75.82%, *SD* = 7.79%) than both the *Current* (*M* = 65.85%, *SD* = 2.46%) and the *Modified Routes with LOA* conditions (*M* = 67.78%, *SD* = 0.56%). Again, the difference between conditions with high traffic featuring a LOA versus the *Baseline* was only 10%. When averaged across all three traffic levels, the *Baseline* condition had the highest average again (*M* = 68.42%, *SD* = 7.39%) compared to both those for the *Current* (*M* = 52.56%, *SD* = 4.70%) and *Modified Routes with LOA* conditions (*M* = 56.62%, *SD* = 1.78%; see Fig 4).

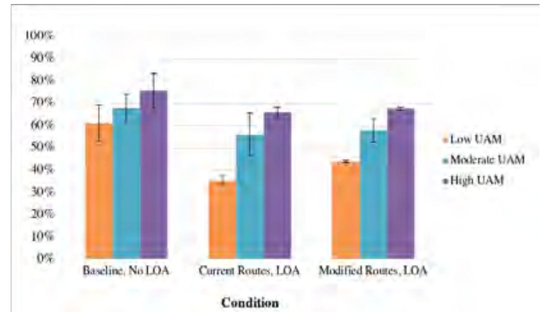

Fig 4. Average percentage of time spent communicating for DFW LE-3 controllers by condition and UAM traffic level.

For DAL Helo controllers (*n* = 2), low UAM traffic produced the highest average percentage of communications in the *Baseline* condition (*M* = 60.07%, *SD* = 5.31%) and reduced by almost half for the *Current Routes with LOA* condition (*M* = 35.25%, *SD* = 8.44%). The *Modified Routes with LOA* condition had an 11% higher average percentage of communication (*M* = 46.06%, *SD* = 2.81%) compared to the *Current Routes with LOA* condition. With moderate traffic, the *Baseline* condition still had a greater average percentage of communication (*M* = 62.44%, *SD* = 6.07%), but the change to the *Current Routes with LOA* condition produced a smaller difference in communication levels than with low traffic (*M* = 43.61%, *SD* = 2.74%). The *Modified Routes with LOA* condition had somewhat larger percentage of communication (*M* = 55.71%, *SD* = 1.49%) than the *Current Routes with LOA* condition. For the high UAM traffic level, the *Baseline* condition's average percentage of communication (*M* = 67.35%, *SD* = 8.44%) and that for the *Modified Routes with LOA* condition (*M* = 61.45%, *SD* = 3.68%) only differed by nearly six percent. Comparatively, the *Current Routes with LOA* condition had the lowest average percentage of communication (*M* = 55.41%, *SD* = 5.06%). When averaged across all three traffic levels for DAL Helo controllers, the *Baseline* condition featured the highest percentage of communication (*M* = 68.29%, *SD* = 6.61%), followed by the *Modified Routes with LOA* (*M* = 54.41%, *SD* = 1.66%). The *Current Routes without LOA* condition had the lowest compared to the other two conditions (*M* = 44.76%, *SD* = 0.75%; see Fig 5).

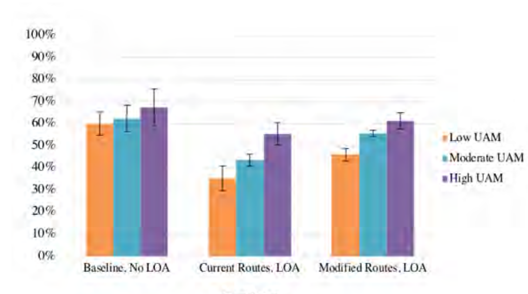

Fig 5. Average percentage of time spent communicating for DAL Helo controllers by condition and UAM traffic level.

With ADS Local controllers (n = 2), low UAM traffic produced similar averages for percentage of time spent communicating across the *Baseline* (M = 29.18%, SD = 2%), *Current Routes with LOA* (M = 26.62%, SD = 3.60%), and *Modified Routes with LOA* conditions (M = 25.82%, SD = 1.55%). With moderate traffic, ADS controllers had the largest average percentage of communication in the *Current Routes with LOA* (M = 36.28%, SD = 2.80%) followed by the *Modified Routes with LOA* (M = 26.99%, SD = 2.25%) and *Baseline* conditions (M = 30.40%, SD = 3.60%). This trend was unique to the ADS Local controllers, as typically both DFW LE-3 and DAL Helo controllers had the highest percentage of communication in conditions where a LOA was not in place. With high traffic, the percentage of communication averages for ADS Local controllers did not significantly differ from *Baseline* (M = 37.93%, SD = 0.18%), to the *Current* (M = 34.43%, SD = 0.31%), and *Modified Routes with LOA* conditions (M = 30.68%, SD = 3.56%). When averaged across all three traffic levels for ADS Local controllers, the *Current Routes with LOA* condition had slightly higher average percentage of time spent communicating (M = 33.44%, SD = 2.35%) compared to the *Baseline* condition (M = 32.50%, SD = 0.47%) and the *Modified Routes with LOA* condition (M = 27.83%, SD = 2.45%; see Fig 6).

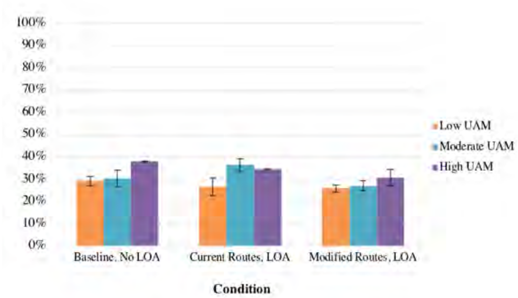

Fig 6. Average percentage of time spent communicating for ADS Local controllers by condition and UAM traffic level.

B. Subjective Metrics

Following the end of each data run, controllers answered questions regarding their communication workload and other issues pertaining to the task of handling varying levels of UAM traffic under different conditions. First, controllers were asked to report the level of pilot voice communications (i.e., both UAM and traditional IFR or VFR), where '1' indicated a very low level, '4' a comfortable level, and '7' an unmanageably high level. When low UAM traffic was utilized in the various conditions, DFW LE-3 controllers reported similar pilot communications levels between the *Baseline* condition (M = 4, SD = 0) and the *Current Routes with LOA* condition (M = 4, SD = 0), whereas the average response was slightly higher within the *Modified Routes with LOA* condition (M = 5, SD = 1.41). However, all averages for the conditions with the low traffic level fell around just above or at a rating value of indicating a comfortable level of pilot communications. With moderate traffic, the average response in the *Baseline* condition (M = 5, SD = 1.41) was slightly higher than that for the *Current* (M = 4, SD = 0) and *Modified Routes without LOA* conditions (M = 3.50, SD = 0.71). The average for the *Baseline* condition was the only one within the moderate traffic level to fall higher than the comfortable level point on the scale. With high traffic, an increase in the average response occurred going from the *Baseline* condition (M = 5, SD = 1.41) to the *Current* (M = 5.50, SD = 0.71) and *Modified Routes with LOA* conditions (M = 6, SD = 1.41; see Fig 7).

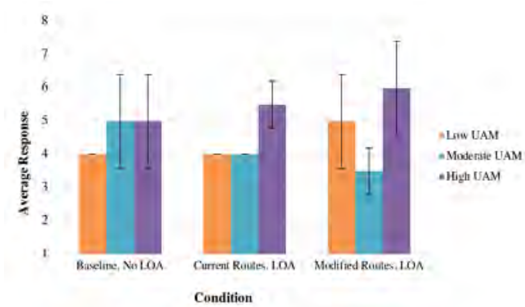

Fig 7. Average responses to "What level of pilot voice communications did you have in this last run?" by condition and traffic level for DFW LE-3 controllers (1 = Very low level, 4 = Comfortable level, 7 = Unmanageably high level).

For DAL Helo controllers, the average response to the level of pilot communication decreased under the low UAM traffic level going from the *Baseline* condition (M = 5, SD = 0) to the *Current Routes with LOA* condition (M = 3.5, SD = 2.12). A small increase occurred going from the *Current Routes with LOA* condition to the *Modified Routes with LOA* condition (M = 4, SD = 1.41). Average ratings for both the *Current* and *Modified Routes with LOA* conditions remained just under or at the comfortable level of the scale, whereas the *Baseline* condition was above the rating for a comfortable level of pilot communications. Under the moderate traffic level, DAL Helo controllers' average response decreased going from the *Baseline* (M = 5, SD = 0) to the *Current with LOA* (M = 4, SD = 1.41), and the *Modified with LOA* conditions (M = 2.50, SD = 0.71). Average ratings for both the *Baseline* condition and the *Current Routes with LOA* condition only differed by one point and fell at or above a comfortable level. However, the average rating for the *Modified Routes with LOA* condition neared the very low-level end of the scale. With high traffic, equal average responses occurred between the *Baseline* condition (M = 5, SD = 1.41) and the *Current with LOA* condition (M = 5, SD = 1.41), indicating that DAL Helo controllers thought the pilot voice communication level was just above a comfortable level. A slight increase occurred going from *Current Routes* to the *Modified Routes with LOA* condition (M = 6, SD = 0), with the average falling nearer to the unmanageably high-level end of the scale (see Fig 8).

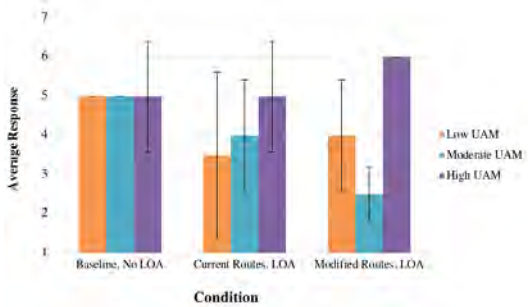

Fig 8. Average responses to “What level of pilot voice communications did you have in this last run?” by condition and traffic level for DAL Helo controllers (1 = Very low level, 4 = Comfortable level, 7 = Unmanageably high level).

For ADS Local controllers, the manipulations featured in the three conditions produced exactly a one-point difference between those that had a LOA versus the one that did not when the low UAM traffic level was used. The highest average response existed within the *Baseline* condition (*M* = 4, *SD* = 0) in contrast to average equal responses between the *Current Routes with LOA* (*M* = 3, *SD* = 1.41) and the *Modified Routes with LOA* conditions (*M* = 3, *SD* = 1.41). With moderate traffic, a similar trend was observed with *Baseline* condition (*M* = 4, *SD* = 0) going to the *Current Routes with LOA* condition (*M* = 3, *SD* = 1.41) and the *Modified Routes with LOA* (*M* = 3, *SD* = 1.41). In both the case of low or moderate traffic levels, ADS Local controllers felt that the *Baseline* condition fell at a comfortable level for pilot voice communications, whereas the *Current* and *Modified Routes with LOA* conditions rested just below. For the high traffic level, the *Baseline* condition had the highest average response (*M* = 4.50, *SD* = 0.71) compared to both the *Current* (*M* = 3, *SD* = 1.41) and *Modified Routes with LOA* conditions (*M* = 3.50, *SD* = 0.71). Ratings remained mostly consistent within the low and moderate traffic levels for the *Baseline* condition. Within the *Current Routes with LOA* condition, responses remained consistent across all three traffic levels. For the *Modified Routes with LOA* condition, responses were equal across low and moderate traffic levels (see Fig 9).

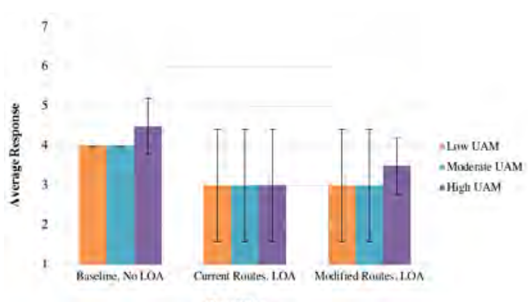

Fig 9. Average responses to “What level of pilot voice communications did you have in this last run?” by condition and traffic level for ADS Local controllers (1 = Very low level, 4 = Comfortable level, 7 = Unmanageably high level).

Controllers were also asked to the rate the frequency of which they contacted or received contact from other participant controllers. A rating of ‘1’ indicated very low level of frequency, with a ‘4’ representing a comfortable level, and ‘7’ suggesting an unmanageably high level of ATC-to-ATC communications. DFW LE-3 controllers, when experiencing low traffic, had somewhat uncomfortable levels of ATC-to-ATC communications in the *Modified Routes with LOA* (*M* = 5, *SD* = 1.41). This was followed by the *Current Routes with LOA* condition (*M* = 4, *SD* = 0) and the *Baseline* condition (*M* = 3.50, *SD* = 0.71), which indicated a comfortable level. With moderate traffic, the *Baseline* condition had a higher average rating (*M* = 4.50, *SD* = 0.71) compared to the *Current* (*M* = 3.5, *SD* = 0.71) and *Modified Routes with LOA* conditions (*M* = 4, *SD* = 0). However, all average responses for these conditions with moderate traffic indicate a comfortable level or just above it. High traffic produced average responses nearer to unmanageably high level on the scale, such that the highest rating occurred for the Modified *Routes with LOA* (*M* = 6, *SD* = 0). The *Baseline* condition (*M* = 5, *SD* = 1.41) and *Current Routes with LOA* condition (*M* = 5, *SD* = 1.41) had equal average responses above the comfortable level (see Fig 10).

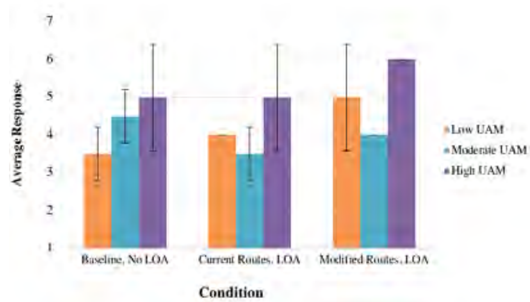

Fig 10. Average responses to “What level of ground communications (ATC-to-ATC) did you have this run?” by condition and traffic level for DFW LE-3 controllers (1 = Very low level, 4 = Comfortable level, 7 = Unmanageably high level).

For DAL Helo controllers, low UAM traffic produced the highest frequency of ATC-to-ATC communications in *Baseline* condition (*M* = 4, *SD* = 0) compared to both the *Current* (*M* = 3, *SD* = 1.41) and *Modified Routes with LOA* conditions (*M* = 3.50, *SD* = 0.71). However, averages fell below or at the rating of a comfortable level. With moderate traffic, the *Modified Routes with LOA* condition did not differ in the average response (*M* = 4, *SD* = 1.41) from the equal average responses between the *Baseline* (*M* = 3.50, *SD* = 0.71) and the *Current Routes with LOA* conditions (*M* = 3.50, *SD* = 0.71). All average responses indicated a comfortable level with moderate traffic. With high traffic, the *Current Routes with LOA* condition had the highest average rating, slightly above a rating indicating a comfortable level of ATC-to-ATC communications (*M* = 5, *SD* = 1.41). Comparatively, the *Baseline* (*M* = 3.50, *SD* = 0.71) and the *Modified Routes with*

LOA conditions (*M* = 4, *SD* = 0) both had responses that indicated a comfortable level (see Fig 11).

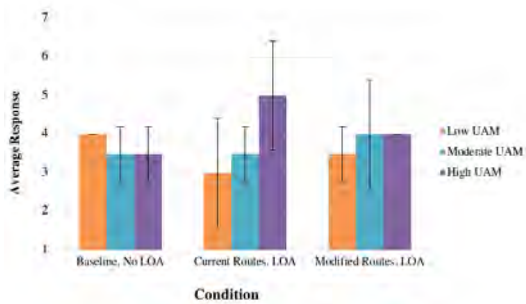

Fig 11. Average responses to "What level of ground communications (ATC-to-ATC) did you have this run?" by condition and traffic level for DAL Helo controllers (1 = Very low level, 4 = Comfortable level, 7 = Unmanageably high level).

For ADS Local controllers, low UAM traffic produced no difference in average responses for the frequency of ATC-to-ATC communications across the three conditions, including the *Baseline* condition (*M* = 2.50, *SD* = 2.12), as well as the *Current* (*M* = 2.50, *SD* = 2.12) and *Modified Routes with LOA* conditions (*M* = 2.50, *SD* = 2.12). All average responses for the three conditions were well below a rating of comfortable level. Moderate traffic created slightly higher averages, especially within the *Baseline* condition (*M* = 3.50, *SD* = 0.71). The *Current Routes with LOA* (*M* = 3, *SD* = 1.41) and *Modified Routes with LOA* conditions (*M* = 3, *SD* = 1.41) saw a slight minor increase in perceived frequency of ATC-to-ATC communications. With high traffic, ADS Local controllers had the highest frequency of ATC-to-ATC communications in the *Baseline* condition (*M* = 4, *SD* = 0), followed by equal average responses between the *Current* (*M* = 2.50, *SD* = 2.12) and *Modified Routes with LOA* conditions (*M* = 2.50, *SD* = 2.12). Average scores never exceeded above a rating of '4' which would indicate a comfortable level of (see Fig 12).

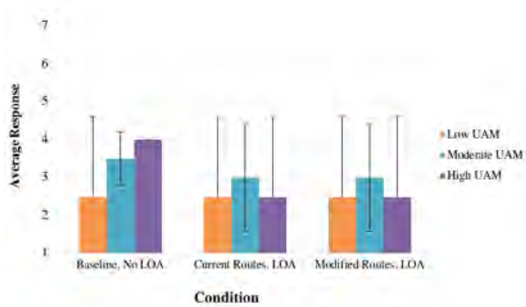

Fig 12. Average responses to "What level of ground communications (ATC-to-ATC) did you have this run?" by condition and traffic level for ADS Local controllers (1 = Very low level, 4 = Comfortable level, 7 = Unmanageably high level).

Controllers answered additional questions about each condition following the end of a block. These questions asked about general opinion on the experimental manipulations regardless of UAM traffic level. First, controllers reported if UAM communications interfered with IFR communications, where '1' indicated that UAM communications did not interfere, '4' represented moderate interference, and '7' indicated frequent interference. DFW LE-3 controllers viewed the UAM communications as having the most interference with IFR communications for the *Current Routes with LOA* condition (*M* = 6, *SD* = 0) followed by the *Baseline without LOA* (*M* = 5.50, *SD* = 2.12) and *Modified Routes with LOA* conditions (*M* = 5, *SD* = 0). Conversely, DAL Helo controllers rated the *Modified Routes with LOA* condition highest in terms of interference (*M* = 3.50, *SD* = 2.12), followed by the *Baseline* (*M* = 2.50, *SD* = 0.71) and *Current Routes with LOA* conditions (*M* = 2, *SD* = 0). Regardless of experimental manipulations, DAL Helo controllers tended to view UAM communications as having little to moderate interference with IFR communications. For ADS Local controllers, the *Baseline without LOA* (*M* = 2, *SD* = 0) and the *Current Routes with LOA* (*M* = 2, *SD* = 1.41) had equal average responses. A slight decrease occurred going into the *Modified Routes with LOA* condition (*M* = 1.50, *SD* = 0.71). However, ADS Local controllers rated interference as being almost non-existent across all three conditions.

Additionally, controllers rated whether UAM communications slowed down their ability to complete other tasks, using a value of '1' to indicate strong disagreement with the statement and a value of '7' to represent strong agreement. DFW LE-3 controllers saw UAM communications as somewhat of a hindrance towards their ability to complete additional tasks in the *Baseline* (*M* = 5.50, *SD* = 0.71), *Current* (*M* = 5, *SD* = 0), and *Modified Routes with LOA* conditions (*M* = 5, *SD* = 0). For DAL Helo controllers, the *Baseline* had the highest average response (*M* = 5.50, *SD* = 0.71), showing moderate agreement towards the presence of task interference. The average responses for DAL Helo controllers tended to lean more neutral in the *Current Routes with LOA* condition (*M* = 3.50, *SD* = 2.12) and slightly above neutral in the *Modified Routes with LOA* condition (*M* = 4.50, *SD* = 0.71). Additionally, ADS Local controllers had the highest average response for the *Baseline* condition (*M* = 4.50, *SD* = 0.71). Responses were lower and equal for both the *Current* (*M* = 2.50, *SD* = 0.71) and *Modified Routes with LOA* conditions (*M* = 2.50, *SD* = 0.71). Generally, ADS controllers were less inclined to believe there was task interference when a LOA was in place.

IV. Discussion

The present study examined whether the implementation of a LOA would reduce communication-associated workload for controllers in a HITL simulation; this was set within a proposed near-term UAM infrastructure for the DFW area, including Dallas Fort-Worth, Dallas Love Field, and Addison air traffic facilities. Current-day, published helicopter routes acted as the foundation of the proposed near-term UAM infrastructure, with modifications of location and separation made to routes for one condition based upon SME feedback. UAM traffic levels varied across runs based upon en route temporal and lateral separation. Current-day communications and procedures for VFR flights within Classes B and D were followed within the *Baseline* condition. The introduction of the LOA with the *Current* and *Modified Routes* conditions adjusted procedural requirements for operations within the DFW airspace by explicitly detailing pre-authorized UAM routes and associated names, providing pre-assigned beacon codes for UAM aircraft, and practicing other steps meant to reduce a controller's general and communication-associated workload.

The *Baseline without LOA* condition featured the highest level of communication with 54.70% of the trial time spent communicating. This was followed by the *Current Routes with LOA* condition with 43.59% and *Modified Routes with LOA* condition with 46.29%. Average percentage of communication dropped at least 10% when a LOA was in place, suggesting some potential benefit to communication workload for controllers.

For DFW LE-3 controllers, the *Current Routes with LOA* condition that featured low UAM traffic provided the least communication load with 35.57% of the time being spent on communication. This was almost half of the time seen in the *Baseline without LOA* condition. The introduction of high UAM traffic in the *Baseline without LOA* condition created the largest communication for DFW LE-3 controllers with 75.82% of the time spent on communication. Implementation of a LOA with high traffic only decreased time spent on communication by roughly 10%. This communication load with greater traffic, regardless of the presence of LOA or lack thereof, is important to consider for projected need for mature (i.e., high-tempo, high-density) UAM operations. Such traffic loads at already burdened facilities like DFW may have an adverse effect on ability to maintain safe operations. When collapsed by condition, DFW LE-3 controllers spent the most time communicating in the *Baseline without LOA* condition compared to the *Current* and *Modified Routes* with at most a 16% decrease in communication occurring with the implementation of a LOA.

DAL Helo controllers had a reduction in communication load with low traffic when a LOA was introduced, going from 60.07% of time spent in the *Baseline* condition to 35.25% of time spent in the *Current Routes with LOA*. This benefit mostly held with moderate traffic where the difference between the *Baseline* and *Current Routes with LOA* conditions was 20%. This difference diminished even more with high traffic, where the *Baseline* and *Current Routes with LOA* condition only had a 12% difference in communication level.

In general, ADS controllers had similar low communication levels across all three condition types when low traffic was used, ranging from 26.62% to 29.18%. Under moderate traffic, time spent communicating was highest in the *Current Routes with LOA* condition, or 36.28% of time spent, compared to both the *Baseline* and *Modified Routes with LOA* condition, which ranged had 30.40% and 26.99% of time spent respectively. With high traffic, ADS controllers had similar time spent communicating across conditions, such that it ranged from 30.68% to 37.93%. While communication levels and subjective viewpoints of communications were similar across conditions for several controller positions, number of UAM managed was higher in conditions that featured a LOA and modifications of the original UAM routes than those using current-day routes without a LOA [6].

One drawback to the time spent communicating metric was the lack of ability to breakdown communications by group (i.e., UAM pilots, the associated position controller, and other ATC-to-ATC communications) due to recording software limitations. Future research on controller communication workload in a UAM setting should examine the distribution of communications across airspace users or players and associated types (e.g., clearances, repeats of commands, step-ons) in order to help identify further opportunities to supplement with procedural requirements or technological assistance.

Subjective metrics revealed that controllers had varying opinions regarding the LOA's impact on communication levels and workload. When asked to report the comfortability level of all pilot voice communications, with traditional IFR or VFR traffic being held constant across all UAM traffic levels, DFW LE-3 controllers found the level to be comfortable in both the *Baseline* and *Current Routes with LOA* conditions when low traffic was used. A comfortable level was also reported in the *Current* and *Modified Routes with LOA* conditions when moderate UAM traffic was present. However, ratings were higher than a comfortable level in all three conditions when high traffic was used, regardless if a LOA was in place. DFW LE-3 controllers' view of UAM communications being at an uncomfortable level directly ties into the earlier finding of higher percentage of communication times across all three conditions with high traffic. These findings suggest significant workload strain for larger air traffic facilities like DFW in a future with mature UAM operations.

For DAL Helo controllers, ratings held consistently above a comfortable level in the *Baseline without LOA* despite varying traffic levels. Additionally, variability amongst DAL Helo controller responses were greater within the *Current Routes with LOA* condition with the average rating indicating a comfortable level of pilot voice communication in the low and moderate traffic levels. Ratings within the *Modified Routes with LOA* condition varied, such that the most comfortable level existed with moderate UAM traffic yet level being reported as almost unmanageably high with the high traffic level.

Conversely, ADS Local controllers almost consistently reported comfortable levels of pilot voice communications across all conditions and traffic levels, with the most comfortable levels occurring in the *Current Routes with LOA* condition. When asked regarding the comfort level of ATC-to-ATC communications, ADS Local and DAL Helo controllers tended to view it as being a comfortable level in most conditions and traffic levels. Conversely, DFW LE-3 controllers reported uncomfortable levels of ATC-to-ATC communications even in conditions featuring a LOA. This finding suggests that DFW LE-3 controllers were still coordinating with fellow controllers at DFW and other surrounding facilities despite the LOA having explicit written point outs, as well as having an active ATIS broadcasting UAM traffic information for heavily congested areas (e.g., Spine Road).

Controllers also had varying opinions on whether UAM communications interfered with both IFR communications and their abilities to complete other air traffic control tasks. When collapsed by condition types, perceived interference of UAM communications with IFR communications was moderate and held constant across the three conditions. However, DFW LE-3 controllers were more likely to view UAM communications as interfering with IFR communications, regardless of whether a LOA was in place. Both DAL Helo and ADS Local controllers reported experiencing less interference overall.

Controllers tended to make fewer reports of UAM communications interfering with other air traffic control tasks. They were more likely to experience task interference in the *Baseline* condition than in both conditions that implemented a LOA. When examined by individual controller position, DFW LE-3 controllers were again more likely to perceive interference with tasks in all three conditions. DAL Helo controllers felt more neutral towards experiencing task interference whether a LOA was used or not. ADS Local controllers were more inclined to report task interference in the *Baseline* condition than in both conditions featuring a LOA.

V. Conclusion

This research explored whether the implementation of a LOA would reduce controller communication-associated workload in a HITL study simulating a near-term UAM infrastructure with varying traffic levels. Current helicopter routes, including modified versions, and communication procedures outlined in the LOA provided a feasible infrastructure for near-term or emergent UAM operations, which will be characterized by low-density and low-tempo. However, ability to scale would be severely limited as higher traffic loads were shown to have a negative impact on controller communication-associated workload, especially for those positioned at heavy traditional traffic facilities like DFW and DAL. Future research will need to examine alternative means for voice communications in UAM operations to further minimize communication workload. This includes controller-pilot data link communications or changes in controller's roles and responsibilities for expected UAM operations. Exploration of additional infrastructure options are also needed, such as replicating frameworks and services used in unmanned aircraft system traffic management.

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