Subjective assessment of Initial and Mid-term UAM operations and the impact on Air Traffic Controllers' workload

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***Abstract*—The emergence of Urban Air Mobility (UAM) marks a new era of aviation that will be characterized by a shift in transportation dynamics marked by safe, efficient, and sustainable air travel within urban areas. Although UAM will provide significant advantages, increased air travel demand has the potential to impact air traffic controllers (ATCo) workload. Therefore, industry, government, and academia in the UAM ecosystem are actively working to overcome potential implementation challenges that include airspace integration and air traffic management. As part of this effort, researchers from the National Aeronautics and Space Administration (NASA) are studying the challenges associated with UAM operations' interactions with air traffic control (ATC). The present research paper presents an analysis of subjective assessments to determine the usability and acceptability of airspace procedures under two different operating conditions – Initial and Mid-Term – and two different levels of UAM traffic. The completion of these investigations will be a steppingstone in supporting the successful implementation of UAM operations into the National Airspace System.**

Keywords—Urban Air Mobility, Air Traffic Control, Workload

I. Introduction

With the introduction of Urban Air Mobility (UAM), air travel is expected to increase rapidly and exponentially over the upcoming years. According to the Federal Aviation Administration (FAA) forecast (see Fig. 1), in year 1- 2, UAM departures may reach a level of 295,530 [1]. This indicates an increase in demand for air traffic control (ATC) services, reflecting the importance of studying current and future airspace structures and procedures that will enhance controller's workload capacity. Therefore, some potential challenges will need to be addressed before initiating commercial UAM services such as air-taxi [2]. These challenges include effectively integrating UAM operations into the National Airspace System (NAS) and identifying areas of improvement concerning air traffic management (ATM).

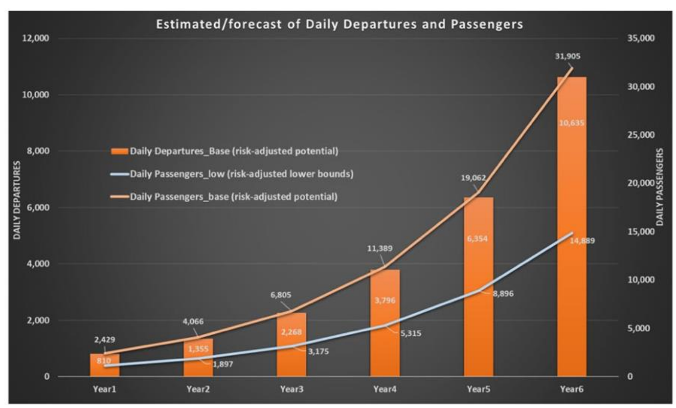


Fig. 1. FAA forecast of daily UAM departures and passengers.

In 2023, the FAA released the UAM Concept of Operations (ConOps) 2.0. This document describes the evolution of the UAM environment (see Fig. 2) and its integration into the current and future airspace [3]. As described by the FAA ConOps 2.0, initial operations will be characterized by low traffic volume and will utilize current FAA Air Traffic Services (ATS) rules and regulations. In contrast, mid-term operations will have increased traffic volume and may introduce cooperative airspace constructs such as corridors. The mid-term environment will require changes to existing regulations and procedures to support UAM operations. Therefore, it will be important to align ATC resources with demand [4].

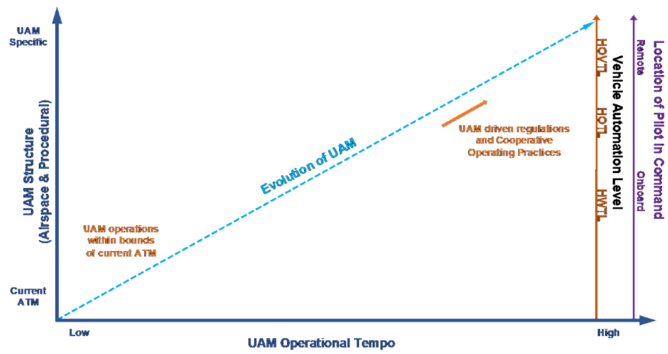


Fig. 2. Evolution of the UAM operational environment.

To evaluate the integration and impact of UAM flights into the NAS, NASA and Joby Aviation collaborated on a human-in-the-loop simulation. The research area centered around Dallas Love Field Airport (DAL), Dallas-Fort Worth Airport (DFW) and the downtown Dallas area. The simulation activity took place at NASA's Future Flight Central (FFC), an emulation of an ATC tower. This paper presents an analysis of air traffic controller subjective assessments to determine whether airspace procedures and information requirements would help manage ATC workload and facilitate UAM operations at DAL and DFW. For a complete list of metrics collected during the simulation and results refer to this publication [5].

II. Methods

A. Participants

Air Traffic Controllers

Four retired air traffic controllers who had previous work experience at DAL and DFW were recruited as participants. Controllers managed traffic in all the simulation runs based on the experimental matrix. There were two positions per airport control tower: Local and Helo. In each tower, controllers changed positions after each simulation run. Responsibilities for the DAL Local controller included handling traffic for runways 13R and 13L, and responsibilities for the DFW Local East-3 controller included handling traffic for runways 17C and 17R. The DAL and DFW Helo positions managed UAM and Visual Flight Rules (VFR) helicopter traffic.

Pseudo-pilots

Eleven pseudo-pilots were recruited to support the simulation, but no research data was collected from them. Participants had an aviation background and were affiliated with San Jose State University.

Before the simulation activity, air traffic controllers and pseudo-pilots received training and had practice runs. Participants were compensated for their time and travel costs.

B. Experimental Design

A 2 X 2 experimental design was conducted to analyze the impact of information requirements and airspace procedures on controller workload. The independent variables were defined by the UAM operational environment (i.e., Initial versus Mid-Term) and UAM traffic density (i.e., Low versus High).

Sixteen counterbalanced runs were completed during the five-day simulation. The Initial operation runs were completed first, followed by Mid-Term operations runs. Each run had a duration of 45 minutes and included additional time for survey completion. Only the Helo positions controlled UAM traffic.

C. Assumptions

Initial Operations

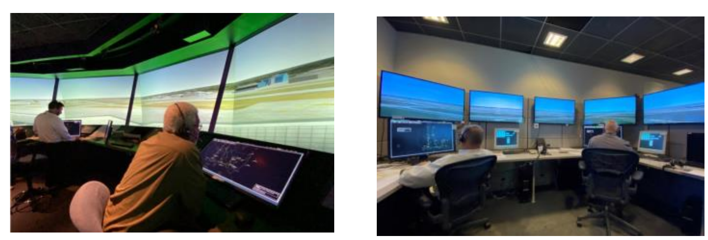
Traffic scenarios for Initial operations used current day VFR in Visual Meteorological Conditions. No UAM-specific airspace structures or procedures were created, and the simulation utilized existing ATS. In addition, a Letter of Agreement (LOA) was utilized to reduce verbal communication between controllers and pilots.

Mid-term operations

Traffic scenarios for the Mid-Term condition introduced new airspace structures, such as corridors and procedures for UAM operations. Two-way communication was not expected during nominal operations inside corridors.

D. Simulation Environment and Setup

The research activity took place at the FFC, a high-fidelity virtual tower facility at NASA Ames Research Center. By using a combination of complex research software, the team was able to emulate air traffic operations in the DAL and DFW airspace environments. DAL was configured within FFC's main tower (Fig. 3a), and DFW was displayed in the "mini-tower" (Fig. 3b).



(a) (b)

Fig. 3. Simulation environment.

E. Radar Simulator

Standard Terminal Automation Replacement System (STARS) consoles were emulated at the FFC. Modifications to these displays included routes for Initial operations conditions (see Fig. 4) and corridors for Mid-Term operations conditions (see Fig. 5).

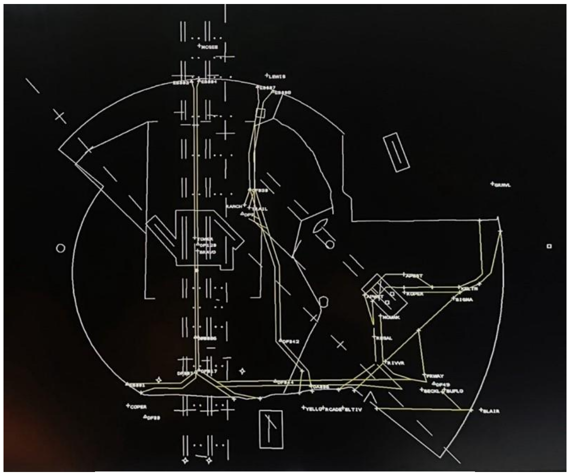


Fig. 4. STARS display for Initial operations.

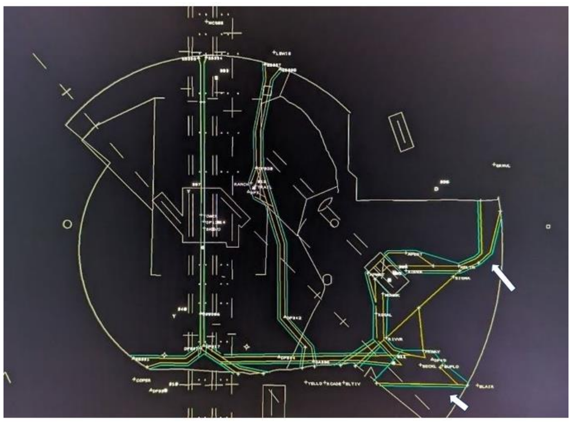


Fig. 5. STARS display for Mid-Term operations. The arrows indicate examples of corridors.

F. Information Presented to Controllers

Initial Operations Condition

UAM flights outside of the Class Bravo airspace featured a VFR limited data tag block format, with only altitude information showing (see Fig. 6). UAM flights inside Class Bravo had a VFR data block with callsign (where pre-assigned beacon codes translated to full callsigns), altitude, and speed in knots. The number 13 indicates the ground speed of the aircraft (130 knots), and the letter V indicates that the aircraft is VFR.

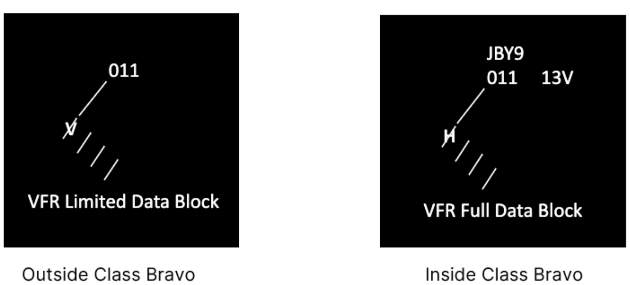


Fig. 6. Data tag formats used for UAM aircraft inside and outside corridors in Initial operations.

Mid-Term Operation Condition

UAM flights outside of the Class Bravo corridors featured a VFR limited data tag block (see Fig. 7). UAM flights inside the Class Bravo corridor showed a VFR data block with only altitude information given and an asterisk symbol to represent the squawked beacon code of 1207.

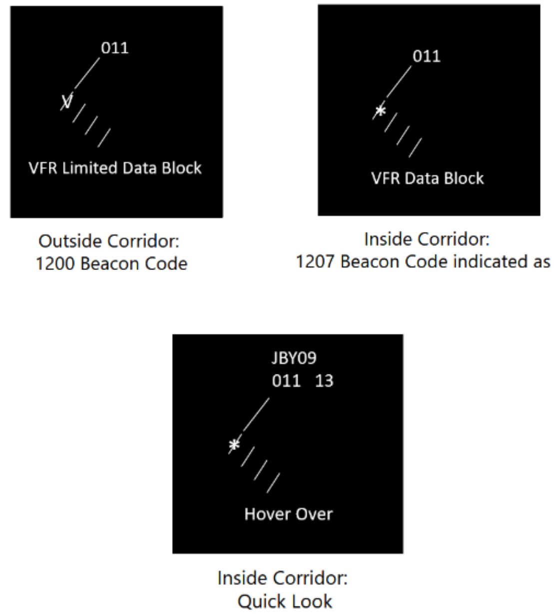


Fig. 7. Data tag formats used for UAM aircraft inside and outside corridors in the Mid-Term condition.

G. Data Collection and Metrics

Subjective data was collected after every run (post-run), after every condition (post-block), and also after the simulation (post-sim). This paper will report and discuss controllers' responses to the NASA-Task Load Index (NASA-TLX) and surveys. Due to the small sample sizes in the data set, no statistical significance tests were conducted.

H. Ethical Consideration

The research study received approval from the NASA Institutional Review Board. Informed consent and public release forms were briefed to the participants. If the participants agreed to continue, signatures were obtained.

III. Results

This study aimed to determine whether airspace procedures and information requirements would reduce ATC workload and facilitate UAM operations at DAL and DFW. Two traffic levels and two operational conditions were used to evaluate the study's objectives. This section reviews the results that helped evaluate these objectives.

A. NASA-TLX Scores

Workload was assessed on a scale from 1 to 5, with 1 representing low and 5 representing high workload on the

NASA-TLX. Regardless of airport control tower, controllers managing the Helo position during Mid-Term operations experienced lower workload than Helo controllers during the Initial operations condition (see Figs. 8 and 9). These findings suggest that the procedures and the LOA provided to the Helo controllers effectively reduced the workload during Mid-Term operations.

When comparing traffic density, workload was perceived to be higher during high traffic conditions, particularly for the DAL Helo and DAL Local controllers (see Fig. 8). Additionally, the DAL Local controller reported higher workload in Mid-Term operations. These results were expected, as the controllers managing traffic at DAL were responsible for coordinating UAM runway crossings at the airport. Results for the DFW Helo controllers indicated that perceived workload was relatively low, except for high traffic conditions during Initial Operations. These results can be due to increased ATC-pilot communications that was also noted in the surveys. In contrast, with all conventional traffic, the DFW Local controller did not experience much change in workload because of traffic density or condition (see Fig. 9). But, when compared to Initial operations, the DFW Local controller reported lower levels of workload during Mid-Term operations. This may be due to the reduction in ATC-pilot communications.

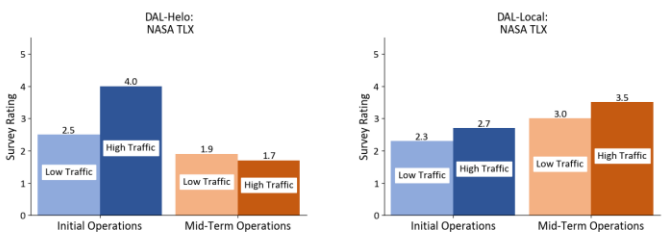


Fig. 8. NASA-TLX workload results for DAL

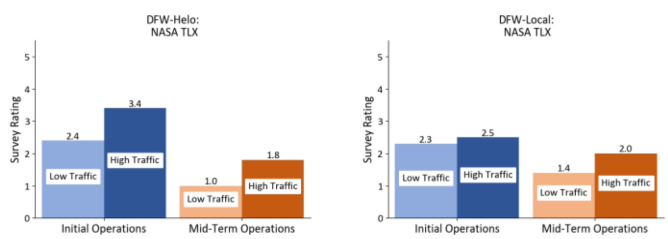


Fig. 9. NASA-TLX workload results for DFW

B. *Survey*

Responses were captured from post-run, post-block, and post-simulation surveys. A scale from 1 to 5 was used, with 1 representing the lowest rating and 5 representing the highest. Comments obtained from open-ended questions will also be discussed in this section.

Acceptability of Procedures

Acceptable procedures is one of the primary requirements for safe and efficient UAM operations. Results from the surveys indicated that across conditions and traffic densities, controllers found procedures to be effective in reducing workload (see Fig. 10). Higher ratings were observed for the Helo controllers during Mid-Term operations (4.8 and above). DFW Local controllers also reported procedures to be high in effectiveness.

The previous results are consistent with survey responses regarding the effectiveness of the routes and corridor structure in reducing workload (see Fig. 11), where ratings consistently surpassed 4.0 except for DAL controllers. Supporting these results are comments from the DFW Helo controllers, which indicated that "*without the procedures, UAM corridor structure and the LOA, the scenario would not even be possible*." However, somewhat lower ratings were reported by the DAL Helo controller under Initial operations (ratings of 3) and the DAL Local controller under high traffic levels. These lower ratings were expected as the DAL controllers noted challenges regarding the coordination of UAM aircraft crossing active runways.

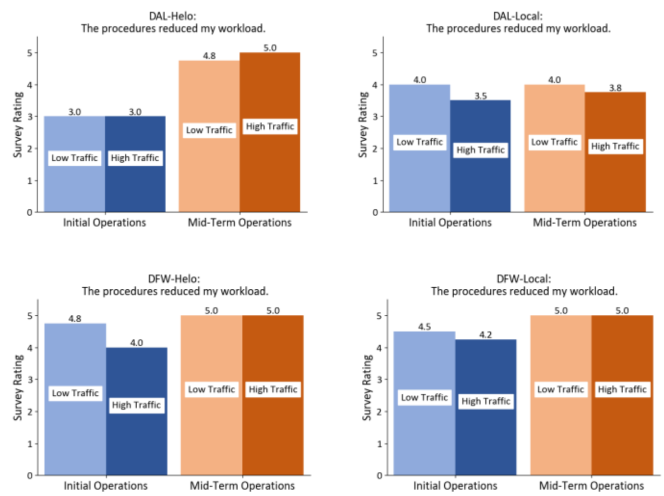


Fig. 10. Survey responses for DAL and DFW regarding the effectiveness of procedures in reducing workload.

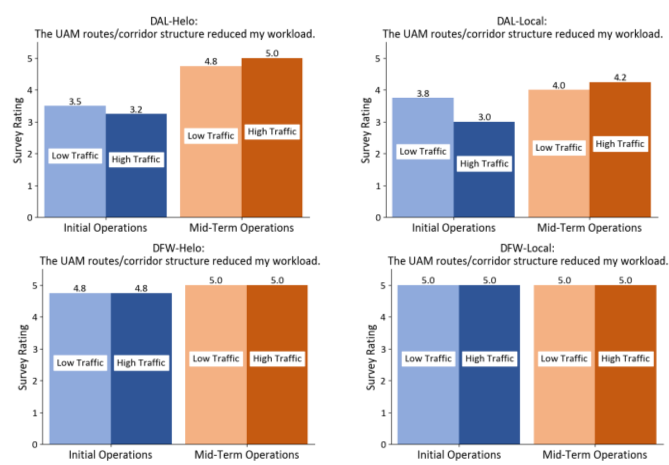


Fig. 11. Survey responses for DAL and DFW regarding the effectiveness of the UAM routes/corridor structure.

Acceptability of Information Requirements

The controller's radar display information was considered sufficient to manage traffic. Average ratings greater than 4.5 were obtained from DAL and DFW controllers under Initial and Mid-Term operations (see Fig. 12). Traffic symbols on the radar display were found to be acceptable for DAL controllers (ratings of 5), and relatively less acceptable for DFW controllers (see Fig. 13). DFW controllers suggested using a different color for the position data tags and having data tags flash if a UAM aircraft strays out of a corridor.

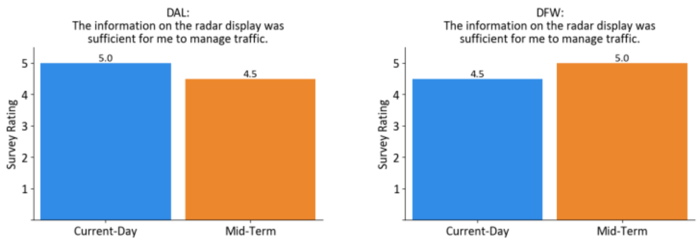


Fig. 12. Survey results for DAL and DFW regarding radar display information and traffic management.

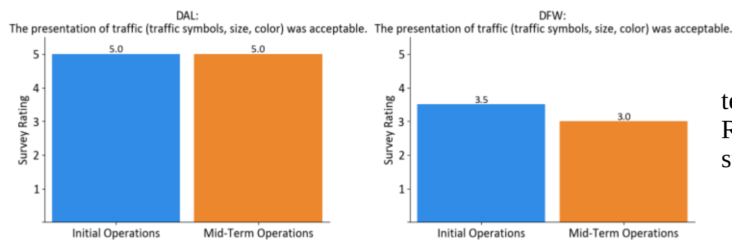


Fig. 13. Survey results for DAL and DFW regarding the presentation of traffic on the display.

IV. Discussion

The simulation successfully explored the effect of procedures and information requirements on ATC workload during two conditions and two traffic densities. Results from the NASA-TLX and surveys indicated that workload was perceived to be manageable across conditions and traffic levels. Compared to DFW, DAL controllers reported slightly higher overall workload. This was expected as the procedures for arrivals and departures at DAL airport required controllers to coordinate runway crossings. As for the information requirements, controllers found the information on the radar display to be sufficient for managing traffic. In addition, traffic symbols were acceptable for both DAL and DFW controllers. Further suggestions include decluttering the radar display and using different colors for the position data tags.

Interest was also placed on Helo controllers during Mid-Term conditions since the operational environment required some changes in the procedures and airspace structure. Under the Mid-Term condition, Helo controllers reported lower levels of workload compared to Local controllers. In addition, survey results supported the effectiveness of procedures in reducing ATC workload while managing UAM operations in and around large airports. The UAM corridor structure and the LOA were also effective in reducing workload as they reduced communications between ATC and pilots.

Due to the nature of the study, data was analyzed for a small sample size. However, future work should consider a larger sample size to conduct statistical significance tests and enhance reliability. In addition, supporting subjective experiences with physiological responses can provide higher accuracy when analyzing and interpreting the results. Despite the limitations, this research contributes to the understanding of ATC workload and information requirements during UAM operations and offers practical suggestions for designing airspace structures and operational procedures for UAM.

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