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Evaluation of Voice vs. Text Communication Modes in Simulated UAM Operations

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ABSTRACT

Urban Air Mobility (UAM) is a system that is expected to operate within and around metropolitan environments, utilizing electric, vertical takeoff and landing (e-VTOL) aircraft, to create on-demand, highly automated passenger and cargo-carrying air transportation services. We report on an investigation of communication modes for pilots flying UAM routes over the San Francisco metropolitan area. The routes consisted of stops at six vertiports, either at airports or other locations, for picking up/dropping off passengers. UAM pilots communicated with air traffic control and vertiport managers using either voice or text messaging. Voice communications were consistent with current day air traffic control operations. Text communications were exchanged via a custom message application that enabled standard messages (requests and responses) to/from ATC via touch input on the tablet. Results showed that communication mode did not affect workload, but voice communications produced higher situation awareness than text communications.

Keywords: Urban air mobility, UAM, Airspace simulation, Voice vs. text communications

INTRODUCTION

Urban Air Mobility (UAM) is a conceptual transportation system that is expected to facilitate on-demand air transportation services for passengers and cargo in urban (and surrounding) areas. Development of the UAM system has been ongoing for several years. It is viewed by some as a novel transportation system for passengers and freight that should relieve urban traffic congestion, while being profitable for UAM vehicle and system developers. There is much optimism associated with this concept, but it is also acknowledged there are many barriers that must be addressed before the societal and commercial benefits can be realized.

Among the more significant barriers to the implementation of the UAM system is the need for integrating UAM flights with our current air transportation system. Recent conceptualizations of the UAM system (e.g. The Boeing Company, 2023; Levitt et al., 2021, 2023) rely on the development of autonomous capabilities for achieving maximum benefits. Most agree that

UAM flight operations initially will require onboard, certified pilots flying routes in compliance with current airspace regulations. Organizations such as Boeing and NASA expect that UAM will transition in the midterm (roughly 2032) to a few remotely piloted vehicles supervised by vehicle operators, combined with special flight procedures to enable automated vertical guidance to and from vertiports. Eventually this will evolve into a fully mature UAM system having many pilotless vehicles supervised by multiple vehicle operators. Increased traffic density will be possible with automated flight operations, and special airspace concepts such as UAM corridors that would be supervised by traffic managers. In addition, flight planning and communications will be automated.

As noted, in the near-term, implementations of UAM services will be operated with onboard, certified UAM pilots flying either VFR or IFR rules. This is a reasonable starting point, except that it creates significant demand for new UAM pilots, which may be problematic due to the current shortage of qualified pilots, resulting from fleet growth, retirement, and attrition (Battiste et al., 2023). Progression in UAM development from current day to midterm operations means that pilots will be an important element in the design of new autonomous systems. Pilots will be required to test automated systems for their suitability in different scenarios, environmental conditions and airspaces, and will serve as a fail-safe function, responding to automation failures. In summary, although the maximum benefits of UAM operations will be realized with autonomous vehicles, onboard pilots and operators will be essential to the design of these UAM systems (Ahuja et al., 2023). The increased demand for trained operators makes this a significant barrier to the success of UAM in the future.

One solution to this barrier is known as simplified vehicle operations (SVO; e.g., Lombaerts et al., 2020). SVO make the vehicle easier to operate and reduces the complexity of flight-system interfaces, which should reduce training time and time to certification. Battiste et al. (2023) suggested that a stability augmentation system coupled with a pathway-in–the sky showing where the vehicle should be flown should reduce the complexity of the manual control needed by the flight task and produce a smooth ride for UAM passengers. SVO can be achieved through a direct mapping of inceptors inputs to task goals – climb, descend, move backwards, etc.

SVO also includes the use of advanced automation for mission management, flightpath management and tactical operations (Wing et al., 2020). Simplifying additional tasks, such as separation management, navigation, and communication, requires research and testing of novel concepts for achieving these tasks and simulation tools for evaluating vehicle interface designs and airspace operation concepts. The BeachCAVE at California State University Long Beach has developed a virtual UAM tool for these purposes. This system is a VisCubeTM M4 CAVE Immersive 3D Display (Visbox, Inc.) that includes a four-wall projection system, an eight-camera advanced real-time full body motion capture system, surround sound, and a graphics workstation. The CAVE system (as opposed to a head mounted display) is appropriate for applications where a wide field of view facilitates a greater sense of immersion in the virtual environment while still allowing participants to interact with physical controls and experience the airspace as if they were sitting in a real cockpit. Moreover, a virtual UAM simulator allows greater flexibility in the design of the vehicle, cockpit interface and airspace, which enables testing of novel concepts of automation.

Previously, two simulation tests of this system have been reported. The initial test of this simulator (Strybel et al., 2022; Ahuja et al., 2023) was conducted using a short flight from the Ferry Building in downtown San Francisco to the San Francisco Airport and back. Both certified pilots and non-pilots were tested. Both groups found the vehicle relatively easy to fly and thought that this system was realistic enough to provide adequate tests of UAM cockpit interfaces and airspace concepts of operation. Subsequently, Haneji et al. (2023) examined the use of tactile alerts for UAM vehicles that were deviating from and automated flight path. In the present paper we report on another test of the UAM virtual simulator, that incorporated a more difficult flight task involving stops at six different vertiports, and controller-initiated clearances requiring pilot acknowledgements during the flight. Two modes of communication were examined, voice and text. For each communication mode we measured pilot workload, situation awareness and performance measures to compare the effectiveness of these modes of communication.

METHOD

Participants

Six participants were tested, all were certified pilots. Two were Certified Flight Instructors II, and three were instrument rated. Pilots reported between 200 and 3500 hours of flight ($M = 981$hrs, SD = 1288 hrs), and two pilots participated in a previous UAM simulation using CAVE VR. Two participants reported experience with virtual reality applications, and two reported experience with remote flight (one flew drones and one flew model aircraft). Participants were paid $50 per hour for participation. The simulation took approximately 4 hours.

Simulation Facility

The virtual UAM vehicle was adapted using Blender, an open-source graphic software (The Blender Foundation), from a quadcopter base model purchased through the Unity Asset Store (Unity Technologies, Inc.) and has been customized via code to enable easier participant control of the aircraft and out-the-window views. UAM operators in the CAVE wore special glasses to facilitate viewing of the 3D simulation with head tracking to automatically adjust the environment to the operators' view. The aircraft can be flown in autonomous or manual mode, and dimensions of the cockpit display were set to conform to the point of view of a seated operator. For additional details on the development and design of the simulated UAM vehicle and test environment, see Marayong et al. (2020) and Shankar et al. (2022).

The vehicle was controlled with an integrated Attack 3 joystick (Figure 1A), which controls all flight parameters (heading, speed, altitude, etc.). The flight stick also supported adjusting the map display and switching between operational modes, either Flight Mode or Ground Mode. In Flight Mode, participants used the joystick to move forward, change speed, climb/descend and control the heading of the quadcopter. Ground Mode was used for the final approach to the landing pad; the participants could move the vehicle forward and backward, laterally, and rotate the vehicle. Moreover, turning, rotating and accelerating could be achieved at slower speeds. The joystick flight control arrangement (Figure 1) approximated SVO concepts described in Wing et al. (2020) for a single joystick based on NASA's EZ-Fly Concept for simplifying V/TOL flight handling, with some exceptions.

The cockpit display (Figure 1) also contained an integrated display of current and assigned flight parameters and a moving map showing vehicle position over the city of San Francisco.

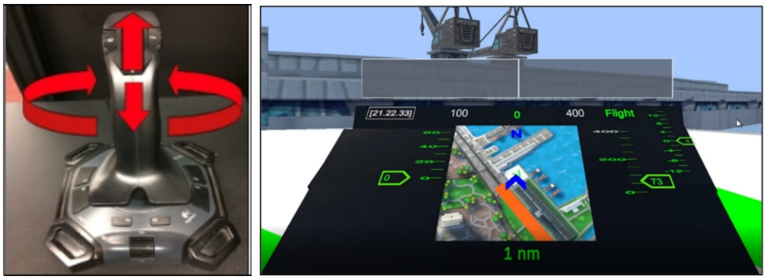
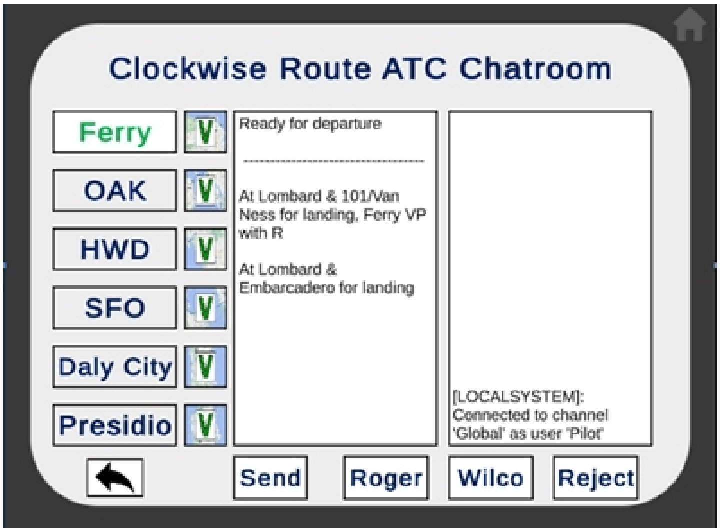


Figure 1: Simplified flight controls (left) and display (right) in the virtual cockpit: the joystick controls vehicle heading, speed, altitude, flight mode, and map zoom; the cockpit interface displays a moving map, heading, speed, altitude, and flight mode.



Ready for departure

At Lombard & 101/Van Ness for landing, Ferry VP with R

At Lombard & Embarcadero for landing

[LOCALSYSTEM]: Connected to channel 'Global' as user 'Pilot'

Figure 2: Message application used for sending and receiving text messages from air traffic and vertiport controllers. The small buttons labelled with V's brought up a map of the specific route leg.

Communication by text was achieved with a messaging application that was developed for pilots. This application was run on a Samsung tablet that was strapped to the leg of the pilot, and functioned as a knee board. An example of the interface is shown in Figure 2. The leftmost column of buttons consists of the vertiports at which the pilots would be flying to. When the vertiport was selected, a set of canned messages were presented for that vertiport in the "Outgoing to ATC" window. The pilot could send a canned message by selecting a message and then clicking the send button. Messages arriving from ATC were shown in the right "Incoming from ATC" window. The pilot acknowledged the incoming message by clicking either "Roger", "Reject" or "Wilco".

In addition to the messages, the messaging application had a set of maps that the pilot could access by clicking the map icon below the vertiport button. This brought up a detailed map of the specific leg of the route, showing required communications, route change landmarks, and changes in airspace class requiring that the pilot Squawk a specific frequency. Note that the ordering of the buttons corresponded to the order of the vertiports the pilot would access on their route.

The application was also available in the voice communication mode, but messages were sent verbally. Pilots could see the text messages, so that they would know what message was required with each leg of the route.

Scenario

Pilots flew circular routes around the San Francisco metropolitan area, stopping at six vertiports. Vertiports were located at either existing airports (SFO, OAK, HWD) or at new vertiports created for this simulation (Ferry Building, Daly City Transit Station, Presidio Park), shown in Figure 3. Each pilot flew routes in clockwise and counter-clockwise directions starting and ending at the Ferry Building Vertiport. Within each leg, pilots would receive flight plan changes from ATC, that consisted of either altitude or speed changes. Pilots were instructed to acknowledge the clearance and then comply with it.

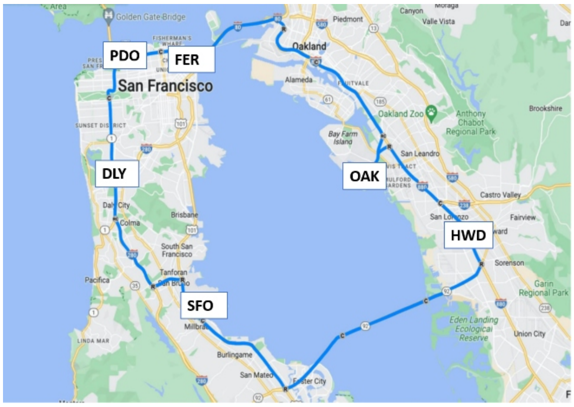


Figure 3: Flights were initiated at the Ferry building in downtown San Francisco and continued around the San Francisco/Oakland area (either clockwise or counterclockwise) with six vertiport stops: FERRY (FER), Oakland Airport (OAK), Hayward Airport (HWD), San Francisco Airport (SFO), Daly City (DLY) and Presidio (PDO).

Procedure

Pilots flew two routes, one clockwise and one counter-clockwise, using voice communications or text communications, for a total of four routes. The communication mode and order of direction were counterbalanced. At each vertiport landing, pilots completed an ATWIT measure of workload (Stein, 985), in which pilots rated their workload on a 1–10 scale (1 = low, 10 = high). At the end of each communication condition, pilots completed the NASA TLX and Cooper-Harper workload instruments, and the SART questionnaire (Taylor, 1990) to measure situation awareness.

Upon arriving at the BeachCAVE lab, pilots were briefed on the UAM concept, and the flight controls for the UAM vehicle. This was followed by practice using the controls and displays in the UAM vehicle and then instructions as to the routes and communication protocols. At the end of the simulation, a custom survey was administered, and this was followed by a debriefing session.

RESULTS

We examined workload, situation awareness and performance on flight time and response times to ATC instructions, using repeated measures analyses of variance (ANOVAs). Separate ANOVAs were run for the clockwise and counter-clockwise conditions in some cases because of the differences in flight demands for the same route leg. For all analyses we adopted a value of $p < .10$ for statistical significance due to the small sample size.

Workload

As shown in Table 1, workload scores were moderate (Grier, 2015). A repeated measures ANOVA on these scores showed all main effects and interactions to be nonsignificant. Overall SART measures of situation awareness were computed based on Taylor (1990); the mean SART score for each condition is shown in Table 1. The main effect of communication was significant ($F(1,5) = 5.65$; $p = 0.06$), with the overall SART score being higher for voice communications ($M = 27.2$; $SEM = 2.2$) compared with text communications ($M = 22.8$; $SEM = 2.0$). The main effect of direction was also significant ($F(1,5) = 7.19$; $p = 0.04$), with SART ratings higher for counter-clockwise flights ($M = 27.2$; $SEM = 1.97$) compared with clockwise flights ($M = 22.8$; $SEM = 2.35$). The interaction between communication mode and flight direction was not significant.

Table 1. Mean workload (NASA TLX) and situation awareness (SART) scores.

Communication Mode	Flight Direction	Mean (SEM) TLX	Mean (SEM) SART
Text	CCW	43.2 (4.1)	24.2 (2.0)
	CW	43.6 (4.0)	22.0 (2.6)
Voice	CCW	45.8 (6.0)	30.2 (1.2)
	CW	46.8 (4.0)	23.8 (2.3)

ATWIT workload ratings were obtained at each vertiport landing, resulting in six ratings per route. Separate ANOVAs were run for each flight direction because the direction of flight produced differences in the length, route complexity and communication requirements. As shown in Figure 4, the interaction of communication mode and flight leg was significant for Counter-Clockwise flights ($F(1, 25) = 3.92$; $p = 0.009$) but not for Clockwise flights ($F(1, 25) = 0.67$; $p = 0.65$). From Figure 4, it appears that ATWIT workload was higher for the FER-PDO and PDO-DLY legs, but all post-hoc comparisons were nonsignificant.

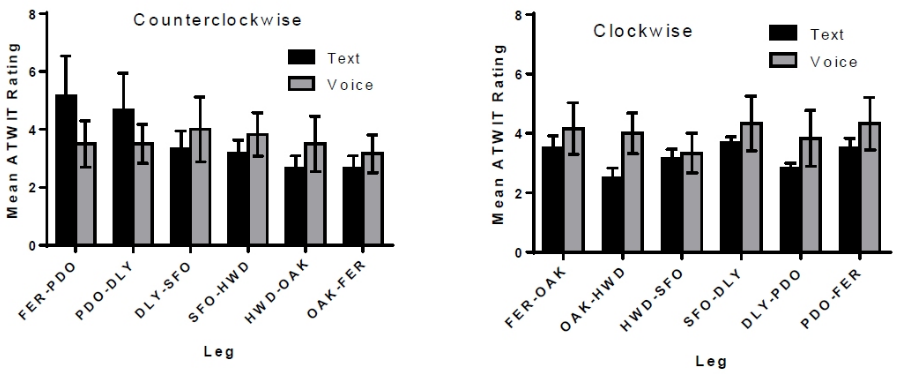


Figure 4: Mean ATWIT ratings for each flight leg. Left: counter-clockwise flights; and right: clockwise flights.

Performance

We examined performance for each communication mode in terms of the number of times the pilot failed to respond to ATC and the time to respond to ATC commands. Whereas only 3% unacknowledged responses were observed in the voice mode, pilots failed to respond to text clearances 30% of the time for counter-clockwise flights, and 45% of the time for clockwise flights. Moreover, the time to acknowledge the ATC instructions was on average 3 times longer in the text mode ($M = 14.5$ s; $SEM = 4.0$ s), compared to voice communications ($M = 1.5$ s; $SEM = 0.11$ s).

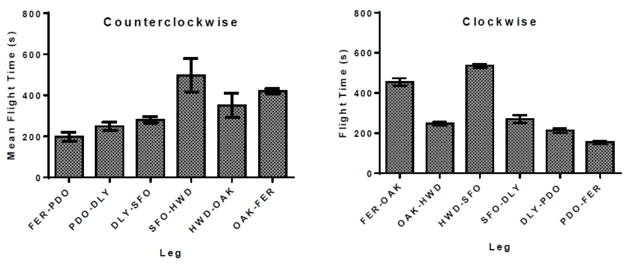


Figure 5: Mean flight time for each route leg. Left: counter-clockwise route; right: clockwise route.

Repeated measures ANOVAs were performed on total flight time for each flight direction with the variables of communication mode, route leg, and direction as factors. For each direction, only flight leg was significant (CCW: $F(5, 25) = 6.12$; $p = 0.0008$; CW: $F(5, 25) = 37.99$; $p < 0.0001$). For both directions, the longest flights occurred between SFO and HWD airports as shown in Figure 5.

Pilot Feedback

Pilot subjective responses to questions about the simulation are shown in Table 2. Pilots used a seven-point scale (1 = "Extremely Unrealistic", 7 = "Extremely Realistic") to rate six questions on the realism of the UAM vehicle, cockpit interface, communications and scenario. In addition, one question asked about the ease of flying (1 = "Extremely Difficult", 7 = "Extremely Easy"). The lowest scores were found for the realism of the cockpit interface and airspace. Pilots were concerned about the lack of information regarding vehicle status, and the novelty of controlling the vehicle with a single joystick. With respect to the airspace, pilots suggested that adding traffic, weather, and winds would improve the fidelity of the simulation environment. Note that pilots rated ease of flying very high (median rating = 6.0).

DISCUSSION

The main purpose of this simulation was to evaluate two modes of pilot-ATC communications, either voice or text. Voice communications were more natural to our pilots, as they were highly trained and experienced with this communication mode. An advantage of text messaging is that it provides a history of previous communications that pilots can refer to if they missed or forgot a specific instruction, but pilots were not familiar with this mode of communication.

Table 2. Summary of subjective ratings at the end of the simulation.

Question	Median	Highest Rating	Lowest Rating
Realistic routes	5	6	5
Realistic Procedures	4	6	2
Realistic Cockpit Interface	3.5	6	3
Realistic Messaging Application	5	7	3
Realistic Airspace	3.5	5	1
Realistic Communications	5	7	2
Easy to Fly	6	7	4

Moreover, pilots failed to acknowledge ATC text messages nearly 50% of the time. However, this high rate could have been a result of the design of the messaging application. If the pilot brought up a map of the current route leg, a message from ATC would not be seen until the specific communication page was made visible again, creating both failures to acknowledge messages and long response times. In future studies, we intend to solve this problem by either adding an audio alert that an incoming message was received, or by displaying the message on top of the current page the pilot was looking at. Another advantage of voice communication was that pilots reported higher situation awareness. Most likely, text messaging produced more head down time, thus reducing overall situation awareness.

We did not find differences in UAM flight times between communication modes. This may be due to the simplicity of the flight controls and the lack of important variables such as traffic, weather and winds, that would increase the difficulty of the flight. We are currently updating the simulation facility to include these factors for future UAM simulations.

Finally, pilots were again positive about the ease of flying the UAM vehicle, suggesting that efforts to implement SVO at least with respect to vehicle handling should be an important direction for early UAM operations that will require onboard pilots.

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