Development of a simulation platform to evaluate integration of UAM traffic into the NAS

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A key premise of emerging concepts for Urban Air Mobility (UAM) is that large numbers of these vehicles will be able to seamlessly integrate into the existing National Airspace System (NAS). In this paper, the development of a simulation capability to investigate ways to overcome this technical challenge is presented.

I. Introduction

Emerging interest in Urban Air Mobility (UAM) operations may soon lead to demand for unprecedented numbers of vehicles operating in the National Airspace System (NAS). An important question is: "How do system developers enable near-term, widespread, safe adoption of these vehicles operating under different procedures and at an anticipated high tempo without destabilizing current NAS operations?" The current Air Traffic Management (ATM) paradigm of IFR and VFR operations with interactive voice communications will not support these operations. Simulations of potential UAM air traffic patterns will be needed to develop and evaluate the procedures required to address this challenge. This document posits an integrated vision for such simulations which includes the simulation of vehicles with emerging capabilities, NAS simulation, human performance monitoring for autonomy teaming, and vehicle-to-vehicle and vehicle-to-NAS communications. All of these are required to evaluate the feasibility of maintaining safe operations in the face of the expected orders-of-magnitude increases in air traffic. The overarching goals of this project are to enable a capability that can help establish criteria and trade-offs for successful and safe UAM integration into the NAS, link progressive levels of integration with required technologies, and dramatically improve communication and networking performance using human-in-the-loop (HITL) testing.

II. Simulation of vehicles with emerging capabilities

Existing airspace simulation capabilities at the NASA Langley Air Traffic Operations Laboratory (ATOL) have been expanded to allow readily-reconfigurable, non-airliner-like, emergent vehicle models with varied levels of autonomy to be directly connected as TestBed nodes to facilitate UAM concept evaluations. These TestBed Use Case Nodes (TUCaNs) are low-fidelity systems designed to enable HITL assessments of rapidly-prototyped emerging vehicle flight models within a representative NAS simulation, see figure 1. The TUCaNs can be used to represent novel vertical takeoff and landing vehicles, helicopters, and conventional aircraft. Each TUCaN would then represent a UAM flight vehicle and would perform candidate missions and operational concepts within the simulation of a busy section of the NAS (i.e., the Dallas Ft. Worth (KDFW) metroplex), to develop and to evaluate NAS compatible UAM

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concepts and procedures, and to demonstrate the impacts of high traffic density UAM operations on the NAS. The ATOL would spawn a NAS simulation with a data feed from the FAA's System Wide Information Management (SWIM) system to properly load the area in question with traffic, and then operate TUCaN UAM simulations within the airspace. The concept anticipates using a standard NAS simulation in the ATOL as a baseline, typically a 45-60 minute scenario replicating a busy metroplex, populated with human controllers operating in the airspace and human pilots operating simulated aircraft. The TUCaNs would be injected (up to three pods, plus up to 17 other human and/or automated piloted workstations) into this NAS simulation and fly per their conceptual routes. Simulations of vertiport operations, including traffic density levels that exceed the capacity for those vertiports would be performed, with an eye out for impacts on the nominal NAS operations occurring in the area. This also supports candidate concepts for NASA's new Air Traffic Management – eXploration (ATM-X) Project research, such as high-tempo, low-altitude UAM operations flying to and from vertiports in a metroplex airspace as well as mixed legacy and new entrant operations by accessing higher-altitude controlled airspace along traditional routes. The TUCaN supports preparations for UAM operational concepts by demonstrating the impacts of high-intensity UAM operations on the existing NAS. These simulations would also enable the exploration of the human interaction component (both pilot and controller) of UAM operations required in a heterogeneously equipped airspace environment.

Fig. 1 Typical TUCaN configurations.

Through a combination of rapid-prototyping and virtual/mixed reality flight deck development for non-airliner-like emerging vehicles, the adaptable TUCaN simulation platform can range from low to medium fidelity to sufficiently test new vehicle interface designs, assess novel operational paradigms, and evaluate interactions between emerging vehicles and traditional commercial traffic in a common representative NAS. HITL simulation testing can examine human-operator-controlled vehicle concepts that include varied levels of onboard automation, vehicle-to-vehicle message management, and equipage levels within the airspace. This includes machine learning efforts for routine and off-nominal message prioritization and auto spectrum sensing in a hybrid communications environment.

III. NAS simulation

The ATOL provides a world-class simulation of the NAS. This facility has been used for ATM research in support of NASA's Aeronautics Research Mission Directorate (ARMD) and the Airspace Operations and Safety Program (AOSP) and its predecessors [1]. The first version of the ATOL began operations around the year 2000, and the capability has grown considerably since then. The ATOL's primary simulation recreates a portion of the NAS to develop and evaluate new ATM procedures. This is done by simulating hundreds of aircraft operating much like those in the real NAS. Select aircraft are flown by subject pilots, typically current or recently retired commercial pilots with a type rating in that particular aircraft model. They utilize a computer desktop workstation that emulates the cockpit displays and controls of the Boeing 777, see figure 2. To properly load the simulated NAS with realistically high levels of traffic, other aircraft are "flown" by confederate researchers and/or retired commercial pilots who operate them as real airline crews would, controlling the vehicles and also communicating with "controllers" via typical (simulated) radio frequencies. Radio communications are an important part of the development of the correct situational awareness for the crews as radio communication — and the awareness a pilot gains by monitoring communication between controllers and other aircraft crews — is obviously a significant aspect of the NAS. The ATOL's reproduction of this radio "party line" is a unique feature of NASA's capability and, according to recent subject pilots, greatly enhances the simulation's realism. The final part of the ATOL communication simulation is live Air Traffic Controllers working in this simulated NAS and communicating to the crews via the simulated radio. The controllers accomplish this using software that emulates Air Traffic Control (ATC) systems running on actual ATC hardware and via the simulated radio, see figure 3. Still other aircraft, not directly a part of the simulation but required to load the system with the proper level of traffic density, are software-driven. Based on questionnaire results and feedback from commercial type-rated pilots who have participated in previous studies, the ATOL has been developed into a dynamic, challenging, and realistic simulation capability for focused air traffic management research. The ATOL facility also has a dedicated UAS lab, designed to explore and develop operational procedures and performance standards for UAS operations in the current NAS. Operations are similar to the other areas of the ATOL as described above, with digital connections to the pilot and controller areas of the lab as required.

Fig. 2 The ATOL pilot room.

Fig. 3 ATOL Air Traffic Control Room.

IV. Human performance monitoring for autonomy teaming

NASA Langley Research Center researchers have developed a Crew State Monitoring (CSM) system focused on improving commercial aviation safety in support of a research program initiated at the request of the Commercial Aviation Safety Team (CAST). CAST identified distraction resulting from attention-related human performance limiting states (AHPLS) as a contributing factor to loss of airplane state awareness (ASA) in a set of 18 commercial aviation accidents and incidents [2]. The CSM team conducted a series of research studies utilizing a suite of sensors to detect and identify the psychophysiological signatures of suboptimal mental states (channelized attention, diverted attention, startle/surprise, and confirmation bias) while pilots engaged in a state-targeted high-fidelity air traffic flight simulation [3, 4, 5]. This work demonstrated the ability to produce real-time classification of targeted states using multiple modalities collected with convenient sensor technologies during scenarios designed to induce AHPLS. The system acquires data to sense brain activity, heart rate, respiration, electrodermal activity, pupil response, eye tracking, and bodily motion. The system was designed in-house to combine passive physiological monitoring with supervised machine learning to produce and visually display an AHPL state prediction once every second, see figure 4. Work is ongoing to expand the sensing modalities within the established system architecture. Further, the states predicted may also be expanded with the addition of appropriate classifier training benchmark tasks. The system is currently being demonstrated to various commercial aviation safety stakeholders and flight instructors to assess potential training methods to mitigate attentional performance decrement and improve airplane state awareness. Beyond current day applications, this system could enable the relay of real-time operator state information to semi-autonomous systems to optimize human-automation interaction and teaming.

Fig. 4 The CSM system's state prediction display prototype.

The addition of this CMS technology to the ATOL simulation platform provides several important benefits to ATM research, as it lends objectivity to self-reported experiences, cuts across cultural differences via consistent biological measures, takes advantage of informative and valuable signals as technology rapidly advances toward sensors that are less obtrusive and easier to apply, and identifies whether performance decrement is due to transient states or chronic issues. It is envisioned that the CSM component of the TUCaN can be applied across various simulation contexts and provide insight into the impact of novel display and controls technology on operator performance. In anticipated future flight operations with commercial aircraft and emergent UAM vehicles as described in this paper, the skill level of the human operators is expected to vary greatly, thus underlining the importance of monitoring highly variable human performance. To collect objective data regarding human experience and performance within these new systems, the TUCaNs will include CSM systems [3, 4] based on psychophysiological monitoring of the human operators to enable coordinated stimulus presentation and mental state prediction.

V. Candidate use scenario

The research will evaluate and demonstrate the impacts of high intensity UAM operations on current NAS operations by simulating high-tempo, low-altitude UAM operations flying to and from vertiports within simulated metroplex airspace. Using the facilities and capabilities already discussed, a NAS simulation of dense metroplex airspace such as the KDFW or Los Angeles (KLAX) areas would be spawned in the ATOL. Piloted TUCaNs would then fly candidate UAM routes at high rates within the metroplex, simulating concurrent takeoff, enroute, and landing operations at representations of candidate vertiports in both nominal and off-nominal situations. Development of suitable routes to accommodate existing NAS operations and restrictions as well as determining unique impacts of emerging vehicles are all easily enabled by these simulations. Concepts for communication can also be evaluated, ranging from current day communication capabilities and procedures, to versions that augment that capability (perhaps with blended voice and data), to more fully automated versions of communication that might not be voiced based.

VI. Future research

Testing emerging vehicle concepts using flight tasks assessed with CSM psychophysiological monitoring technology can help identify areas that may induce hazardous states of awareness prior to higher cost full-scale simulation and flight testing. Using TUCaNs to train for UAM missions could leverage mixed reality to simulate operational tasks with operational stressors, rather than simpler fit-to-fly cognitive assessments. Biofeedback can be used during initial training, maintainer training, or simply overall cognitive improvement. Longer-term, enabling vehicle-centric operator state awareness supports improved human-autonomy teaming beyond current human-automation interactions.

VII. Conclusion

The newly developed flight simulation capabilities within the TUCaN system are designed to enable UAM operations. NASA Langley researchers have identified a future need, developed a concept to mitigate the issue, built hardware and software to leverage existing tools to simulate the environment, included unique but critical capabilities such as voice communication and biofeedback, and have plans to conduct research. This research will enable evaluation of emerging UAM operational concepts in realistic representations of current operations, helping to pave the way towards safe and efficient UAM operations.

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