A Remote Vehicle Operations Center's Role In Collecting Human Factors Data

Bill K. Buck[1], Eric T. Chancey[2], and Michael S. Politowicz[3]
NASA Langley Research Center, Hampton, VA 23681, USA

James R. Unverricht[4]
National Institute of Aerospace, Hampton, VA 23666, USA

and

Steven C. Geuther[5]
NASA Langley Research Center, Hampton, VA 23681, USA

The National Aeronautics and Space Administration is supporting research to develop a prototype remote vehicle operations center at Langley Research Center to explore current and future advanced air mobility operations using small unmanned aerial systems vehicles as surrogates for future, larger-scale passenger carrying vehicles. Data collected within the Remote Operations for Autonomous Missions (ROAM) Unmanned Aerial Systems (UAS) Operations Center will be used to explore different roles and responsibilities of remote operators managing multiple autonomous vehicles, with the goal of exploring human-autonomy teaming concepts that enable *m:N* operations (i.e., *m* operators managing *N* vehicles). ROAM has developed into a world-class research, development, and technology (RD&T) environment that can support both the collection of human factors data and the command and control of remote vehicles in beyond visual line of sight conditions. Presented in this paper is an overview of ROAM, with a focus on the design components that support human factors data collection and a review of initial usability results of the facility.

I. Introduction

Interest in Advanced Air Mobility (AAM) has increased significantly in the past several years around the world. AAM operations are envisioned to include passenger transport, local and regional cargo transference, inspection and surveillance events, and emergency response activities [1]. The number of flights, both locally and regionally, of the foreseen AAM operations will rise well above the traffic density seen in today's airspace environment. To conduct these operations in a safe and efficient manner, a major, yet unresolved, paradigm shift is required that transfers localized operations of autonomous vehicles to a remote operations location capable of multiple vehicle management with fewer operators using autonomous systems where applicable. Significant research is required to understand the implications of this transfer of operations within the aviation ecosystem.

The National Aeronautics and Space Administration (NASA) Langley Research Center (LaRC) is developing a prototype remote vehicle operations center, named ROAM, to conduct research into current and future AAM operations using small unmanned aerial systems (sUAS) as surrogates for AAM vehicles. This research is intended to provide data that informs evolving operational concepts, aviation regulations, and standards. Presented in this paper is an overview of ROAM, with a focus on the design components that support the collection of human factors data and a review of initial usability results of the facility. These data will be used to evaluate different roles and

---

[1] Aerospace Engineer, Crew Systems and Aviation Operations Branch, M/S 152, AIAA Senior Member.
[2] Human Factors Psychologist, Crew Systems and Aviation Operations Branch, M/S 152.
[3] Aerospace Engineer, Crew Systems and Aviation Operations Branch, M/S 152, AIAA Member.
[4] Human Factors Psychologist, Crew Systems and Aviation Operations Branch, M/S 152.
[5] Aerospace Engineer, Aeronautics Systems Engineering Branch, M/S 238.

responsibilities of remote operators managing multiple autonomous vehicles, with the goal of exploring human-autonomy teaming (HAT) concepts [2] that enable *m:N* operations (i.e., *m* operators managing *N* vehicles). The NASA facility's human-centered design process is focused on enabling users with well-defined roles to satisfactorily meet their responsibilities in a safe and efficient manner when remotely operating sUAS vehicles.

II. Background

Many of the AAM mission types will leverage vertical takeoff and landing aircraft (VTOL), and therefore vertiports (i.e., "identifiable ground or elevated area, including any buildings, or facilities thereon, used for the vertical takeoff and landing" of an aircraft) [3] become an important operational component to consider. Key barriers for AAM operations in the vertiport domain include a lack of: standardization around required technologies and performance to support high-tempo and high-throughput Urban Air Mobility (UAM) business cases around vertiports; mature concepts, procedures, and technologies supporting automated approach and landing; automated merging and spacing; and automated contingency decision making for electric vertical takeoff and landing (eVTOL) operations in vertiport environments. A barrier also exists in the development of evaluation and testing practices necessary for demonstrating that automated mitigations warrant satisfactory means of compliance to existing or future safety regulations. This is particularly true for the use of automation to support beyond visual line of sight (BVLOS) operations for unmanned aerial systems (UAS). Furthermore, a key barrier exists for required data information exchanges among the aircraft, airspace service provider, and the vertiport systems to support increasingly dense operations.

At NASA, within the AAM Project, research and advancements are focused on the delivery of aircraft, airspace, and infrastructure system and architecture requirements to enable sustainable and scalable medium-density AAM operations. Within the AAM mission portfolio, the High Density Vertiplex (HDV) subproject ("vertiplex" indicating multiple vertiports in a local region with interdependent arrival and departure operations) is delivering the development and testing of concepts, requirements, software architectures, and technologies needed for the terminal environment around vertiports [4]. A significant aspect supporting this work entails standing up a remote UAS operations center (i.e., ROAM), which will eventually enable a crew of human operators to remotely manage multiple highly automated sUAS in BVLOS conditions. NASA's Transformational Tools and Technologies - Revolutionary Aviation Mobility (T^3-RAM) subproject has identified human-autonomy teaming as a critical area of research required to enable remote aircraft operations in the context of AAM [5], such as those being explored by HDV in ROAM. Under T^3's Autonomous Systems Enduring Discipline, the HAT Foundational Activity [6] has worked closely with HDV to provide human factors research and design support that facilitates humans and machines working and thinking together, with the specific purpose of exploring and advancing remotely operated UAS concepts in ROAM.

III. Description of NASA's ROAM UAS Operations Center

The ROAM UAS Operations Center has a twofold purpose: (1) to conduct human-in-the-loop experiments that explore different roles and responsibilities of remote operators managing multiple increasingly autonomous vehicles, with the goal of exploring human-autonomy teaming concepts that enable *m:N* operations, and (2) to enable multi-vehicle small UAS flight operations from a remote location in BVLOS conditions. Use cases tested within the facility focus on sUAS operations (e.g., package and food delivery, emergency response, and surveillance and reconnaissance) and passenger-carrying operations (e.g., UAM). As BVLOS operations in the national airspace system become more common, it is important to understand how humans can effectively team with technology in a manner that supports user business models highlighted in these use cases.

A. ROAM Design Philosophy

The overarching design goals for ROAM are to relocate existing field operators to the remote vehicle operations center, produce a shared situation awareness environment for participating personnel, and provide the ability to pursue advanced vehicle operations and control supporting AAM and other various research activities. The remote operations center is envisioned to provide a user training environment, flight operations planning and briefing environment, and a research facility for conducting simulated and live operations of sUAS vehicles. Airworthiness, safety, and mission assurance considerations and constraints for the design of ROAM are driven by project requirements and existing NASA policies, procedures, and regulations. Considerations for flight operation include safety of flight for the vehicle, the local airspace, and people on the ground below and near the vehicle's flight path. These design goals and constraints bound the technical solution space of ROAM.

The ROAM UAS Operations Center is implemented using a role-based ontology approach to define a logical and structured methodology to define the overall facility design based on the roles and responsibilities of personnel expected to use the operations center. The role-based ontology approach for designing ROAM is purposefully applied iteratively and recursively. To that end, as more unique roles are identified to be included in ROAM, the workstations, layout, and data sources available are extended. Additional capabilities allow for a more enriched research environment to support human factors data collection for operations (live and simulated) conducted within ROAM.

At NASA Langley Research Center, the concept of a small-UAS operations center has been an evolutionary process beginning with a simple desk setup to monitor a remote vehicle's telemetry from inside a research complex building [7]. This early "remote GCSO" was able to observe live operations at CERTAIN, which laid the foundation for future needs and capabilities to be explored. As the AAM-HDV subproject gained ground in its early development, the need for a larger facility to support more remote operators and to study their needs and role was required, leading to this first command and control instantiation of the ROAM UAS Operations Center.

B. ROAM's First Instantiation

The ROAM UAS Operations Center is located within the Air Traffic Operations Laboratory (ATOL) at NASA LaRC. ROAM supports both simulated and live vehicle flight operations, which are also conducted on the designated flight range at LaRC called the City Environment for Range Testing Autonomous Integrated Navigation (CERTAIN) [8], allowing for flight operations in a wide array of environments. By utilizing LaRC's buildings and landscape, operations within CERTAIN can be used to study the difficulties of highly automated flights in challenging scenarios. The AAM-HDV subproject plans to build up test infrastructure, sensors, radio communication, and cloud-based services to demonstrate an automated vertiport environment. A generalized layout for ROAM is presented in Fig. 1. The design of ROAM and its layout is intended to support workstation areas for the Ground Control Station Operator (GCSO), Range Safety Officer (RSO), and the Flight Test Manager (FTM) or Simulation Director (SD). At full build-out of its initial phase, ROAM will be able to support six workstations, three of which will be dedicated for GCSOs to remotely manage sUAS vehicles. It will be noted that during the usability study that is discussed later within this paper, GCSO workstations #2 and #3 were not present and the desks farther from the forward video wall that are normally designated for positions like the RSO were occupied by human factors researchers.

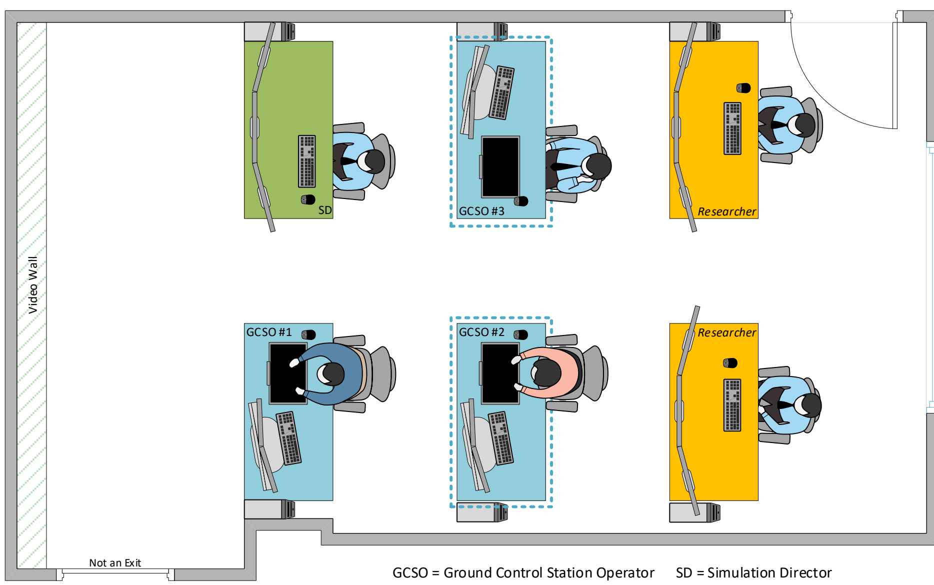

Fig. 1 ROAM UAS Operations Center Generalized Layout, 2021

The roles and responsibilities of the personnel within ROAM during simulated and live flight operations is varied, and each role has a workstation with a layout and various data sources that personalize the workstation to suit their needs. In addition to individual workstations, the ROAM UAS Operations Center is equipped with a large-format video wall forward of the room to provide occupants and observers a central point for shared situation awareness and briefings (e.g., pre-flight and post-flight). Figure 2 and Fig. 3 illustrates the workstation layout for the GCSO and SD roles within the ROAM UAS Operations Center, as of July 2021.

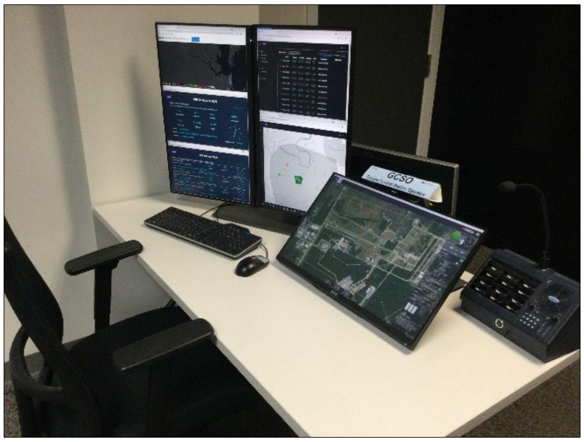

Fig. 2 GCSO Workstation

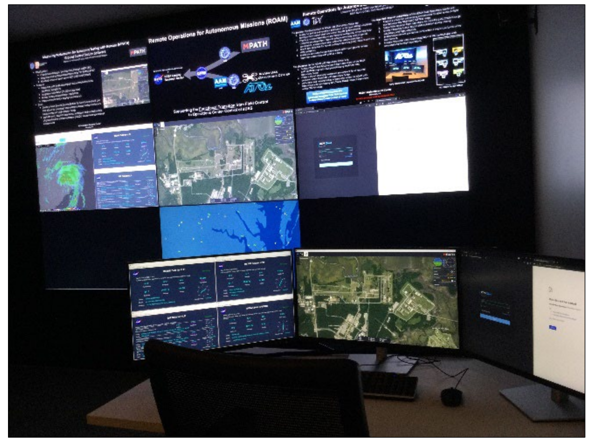

Fig. 3 SD Workstation with Video Wall

Figure 4 presents the layout, with functional parts labeled, for the GCSO's workstation that was used by the participants in AAM-HDV's AOA Simulation [9]. Each workstation is part of the physical space design within ROAM, supporting the user's needs and assigned role(s) for flight operations (live or simulated). Several guidelines were considered in the workstation design, including keeping the displays of information simple and in a consistent presentation format while facilitating the user's movement among the output sources (although limited by some of the research applications in use). It is important that the workstation is easily reconfigurable and interchangeable, dependent on the needs of planned activities for a specific day or week. Flexibility was proven key and services running within ROAM should be capable of display on each workstation, dependent on the user's role.

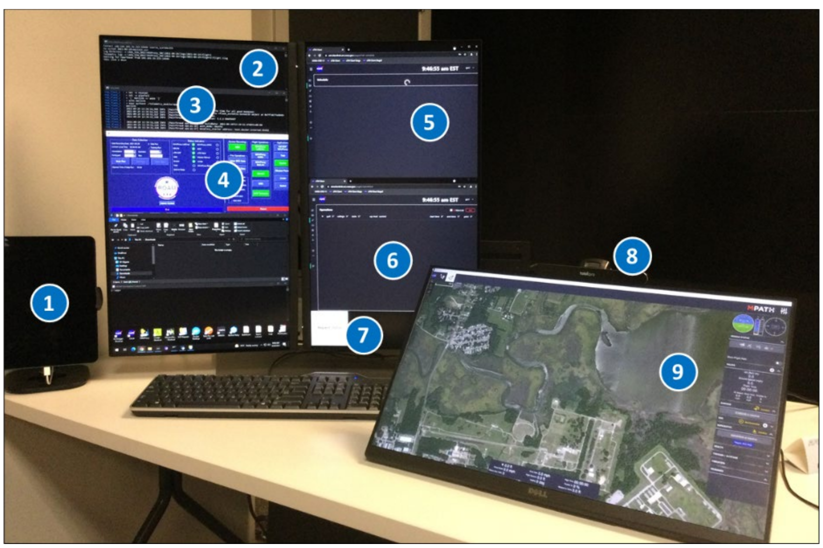

Fig. 4 Initial GCSO Workstation Layout for AAM-HDV AOA Simulation

Also included within Fig. 4 are several numbered identifiers matched to the list below. For the GCSO workstation, the primary focus is the MPATH (Measuring Performance for Autonomy Teaming with Humans) Ground Control Station (GCS) software [6]. Supporting the GCS software is the Extensible Traffic Management (xTM) Client, a cloud-based research-software that is currently under continued development by the NASA AAM-HDV subproject. Additional supporting information sources are located on the other screens.

1. iPad for Human Factors Questionnaires
2. Vehicle Telemetry Status
3. xTM Telemetry Module
4. ROAM Workstation Control
5. xTM Client (Map View or Schedule View)
6. xTM Client (Operations View)
7. Button to Activate Automated Landing
8. Eye Tracker
9. MPATH Ground Control Station

An important aspect of the design space for ROAM is the promotion of a shared situation awareness among all users and researchers within the room. ROAM includes common services that support the display of information to a user across multiple roles and a capability for users to share information from their individual workstations. This is accomplished with the use of a video wall composed of multiple monitor displays located in a position viewable from all individuals present in the room. The video wall is comprised of a three-by-three grid of large format monitors that can support multiple layouts and configurations of information data sources. The video wall can be used during pre- and post-flight briefings for an operation; it serves as the common source of information during a flight for users and visitors to ROAM; and as a central messaging location by the FTM, SD, or RSO to communicate planned or unplanned changes. Figure 5 presents the video wall as it was used during the AOA Simulation for data collection with only one GCSO operating.

Fig. 5 ROAM Forward Video Wall as used in AOA Simulation

C. Capabilities Supporting Human Factors Research

The GCSO workstation is the primary information and interaction location for the GCSO. Within Fig. 4 above, the angled touchscreen (also allowed for mouse-based interactions) is the primary GCSO display and presented the MPATH GCS interface. Modified from the open-source QGroundControl software [11], MPATH is a software application developed by NASA (T^3-RAM) for controlling Micro Air Vehicle Link (MAVLink)-enabled sUAS (see Fig. 6 for a closeup of the user interface). MPATH was designed to improve baseline QGroundControl usability by facilitating close spatial proximity of related information, increasing automation transparency, and supporting routine human factors data collection by logging user interaction data.

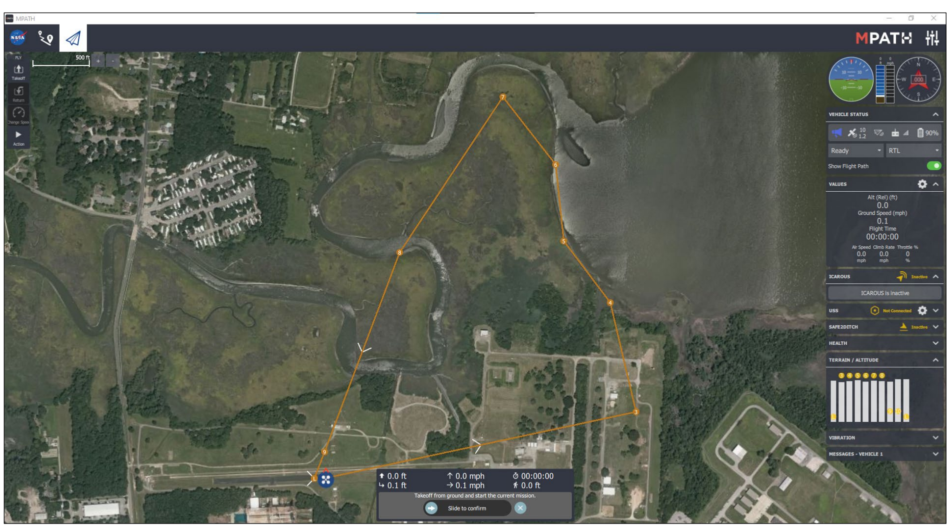

Fig. 6 MPATH Ground Control Station User Interface

A Tobii Pro Nano eye tracker mounted on the display monitor with MPATH can be used to measure GCSOs' eye movements (see Ref. [12] for eye tracker specifications) for that display only. Eye movements are recorded at a sampling rate of 60 Hz and analyzed with Tobii Pro Lab [13]. Because this is an off-body eye tracker, GCSOs can freely move around without restriction. The goal of the eye tracking data is to explore naturalistic eye gaze behaviors of GCSOs in ROAM. This unobtrusive approach allows the GCSO to move freely, look away from the MPATH GCS screen, and modify the configurations of the display elements. See Ref. [14] and [15] for eye tracking results from operations in ROAM.

Apple iPads are located at GCSO workstations to collect questionnaire data from operators. A custom iPad app was developed by NASA (T^3-RAM) and has been used to record responses of the workload, situation awareness, and perceived risk questionnaires [7]. Additionally, usability results for ROAM, which are presented in Section IV, have been collected from GCSO participants with this application. Figures 7 and 8 present a sample of the questionnaires displayed on the iPad within ROAM.

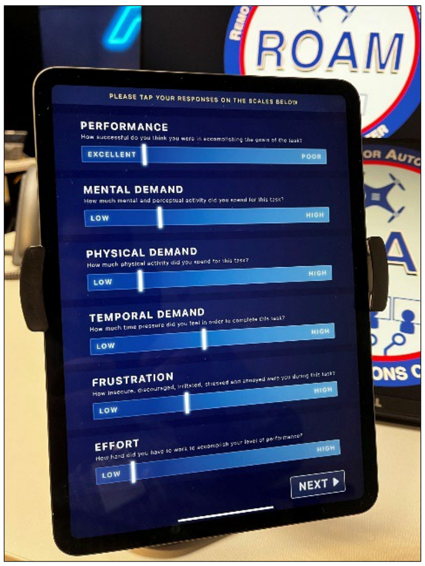

Fig. 7 iPad Post-Scenario Questionnaire Example, NASA-Task Load Index (TLX) [16]

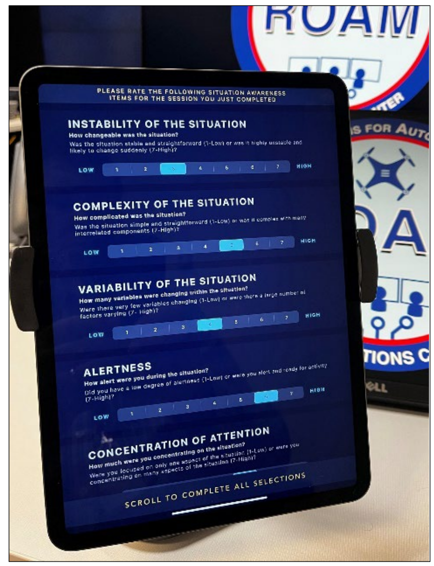

Fig. 8 iPad Post-Scenario Questionnaire Example, Situation Awareness Ratings Technique (SART) [17]

IV. Initial Usability Results

The NASA AAM-HDV AOA Simulation [9] was the first command and control activity for the ROAM UAS Operations Center, assessing the initial limits and data connections established over the Summer of 2021. The AOA Simulation ran for twelve days between September 30 and October 19, 2021, taking approximately 115 work hours, with six GCSOs as participants (one at a time) from NASA LaRC. Nine different scenario types were tested using various technological components within the HDV system [9]. During this hardware- and human-in-the-loop (HHITL) activity, 108 scenarios were completed between training and data collection runs across all participants for a total of 15 hours of simulated vehicle flight time. Data was collected from the vehicles, workstations, and participants during the AOA Simulation. This section presents initial usability results of the ROAM UAS Operations Center.

The NASA research team employed an inductive approach that relied on observing fewer participants than a deductive approach under as many test conditions as feasible (i.e., this study did not employ an experimental design). Six male LaRC GCSO personnel (M_{age} = 37.33 years, SD_{age} = 9.27) participated in this study, which included both NASA Civil Servants and contractor employees supporting the NASA AAM-HDV subproject. This sample size was selected based on one of the goals of the AOA Simulation research activity, which was to discover as many issues as possible with the ROAM workstation within available resourcing limits. The goal was not to test hypotheses [deductive approach] with inferential statistics, which generally requires higher sample sizes to achieve adequate statistical power to observe effects of a given experimental design on dependent variables with *a priori* selected effect sizes. Specifically, the research team sought to test no more than 6 users under as many scenarios as feasible given testing constraints (see Ref. [12] and [13]).

Participants did not receive any direct benefits for participating. This research complied with the American Psychological Association Code of Ethics and was approved by NASA's Institutional Review Board. Informed consent was obtained from each participant.

The initial usability of the ROAM UAS Operations Center is summarized by the data collected from the participants with a modified version of the Post-Study System Usability Questionnaire (PSSUQ) [20] from the HDV AOA Simulation. The PSSUQ is a 16-item measure with three factors: Usability, Information Quality, and Interface Quality; however, the research team decided not to collect the Interface Quality factor for ROAM because it was not a standalone software application. The range of the index values was from 1 to 7, with 1 being the lowest rating and 7 being the highest rating. All six GCSOs responded to the items within the digital questionnaires, and some provided comments to accompany those ratings. Responses from the PSSUQ questionnaire indicated that ROAM was rated very high on Usability and Interface Quality factors and is illustrated in the following figures. A collective summary of the PSSUQ results for ROAM is presented in Fig. 9. Figure 10 presents the average with standard deviations identified for the Usability Index for ROAM. Figure 11 presents similar information gathered from participants on the Information Quality Index for ROAM.

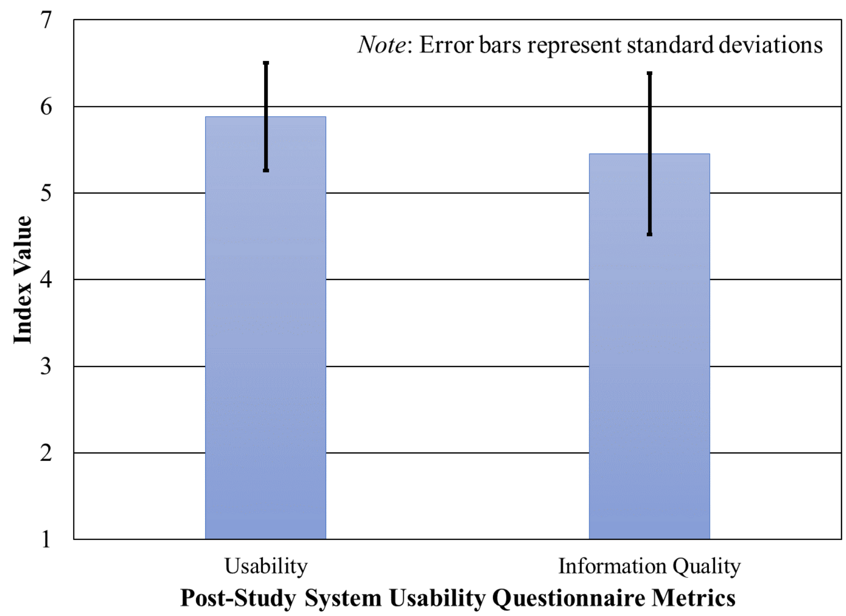

Fig. 9 Average ROAM PSSUQ Results for Usability and Information Quality (n = 6)

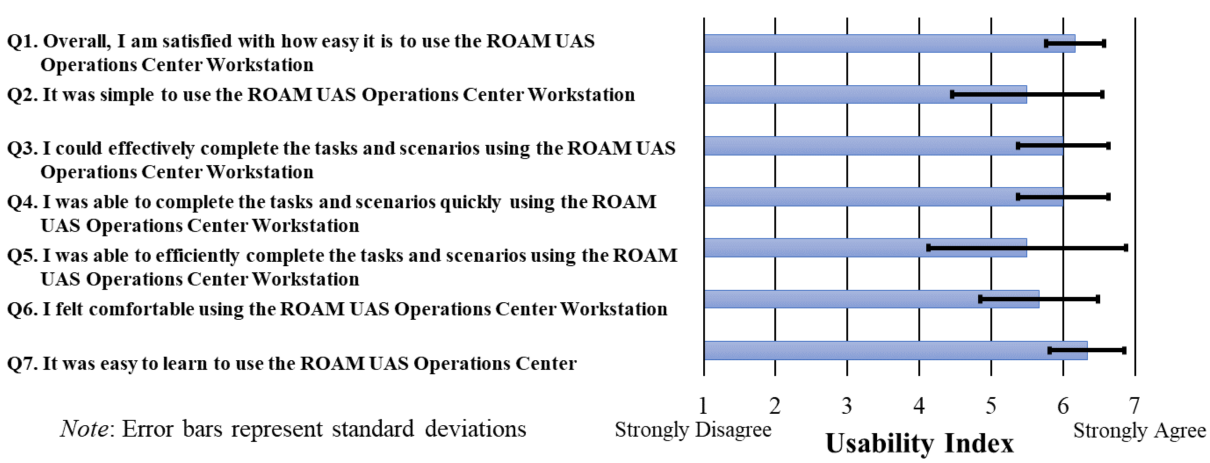

Fig. 10 Average Usability Item Ratings from AOA Sim (n = 6)

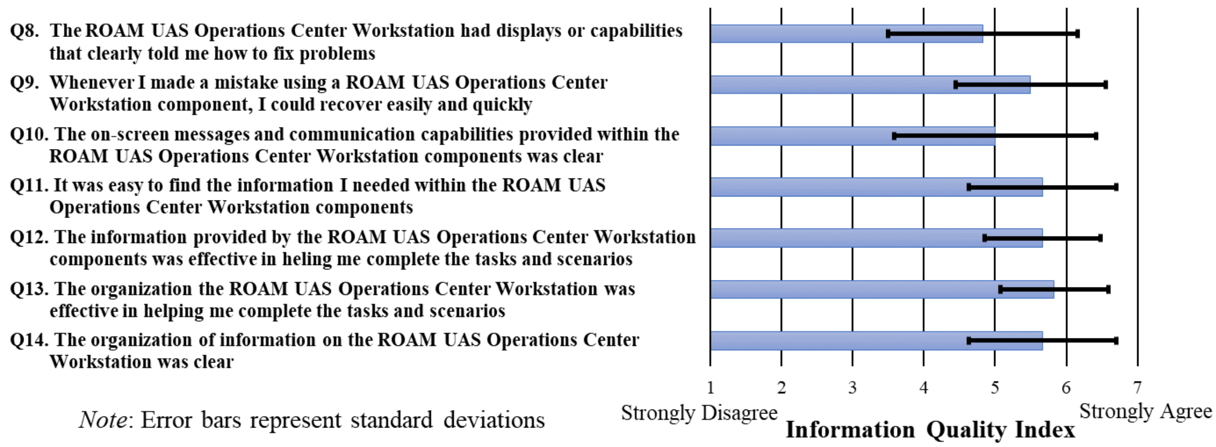

Fig. 11 Average Information Quality Item Ratings from AOA Sim (n = 6)

Results indicated GCSO performance and usability ratings may be improved further with additional training and experience within ROAM (i.e., AOA Simulation was the first use of ROAM). The research team also concluded that integration and grouping of similar operational information could improve usability and performance more generally. Specifically, the primary GCSO display (i.e., MPATH) and the scheduler display with traffic management tool (xTM) information needs to be integrated into a single display to avoid dividing attention (i.e., a violation of the proximity compatibility principle [21]) across multiple displays, which can lead to visual attention failures such as change blindness [22].

Overall, participants rated the ROAM UAS Operations Center as highly usable. Based information gathered from the PSSUQ, ROAM received very high ratings in learnability, satisfaction, effectivity, and efficiency. Additionally, participants highly rated ROAM's information quality. However, two items did lower ROAM's overall information quality. First, designers need to ensure that ROAM displays communicate how to alleviate a problem, rather than simply state that a problem exists. Effective warnings include not only a description of the hazard but also instructions on how to avoid or fix the hazard [17]. Second, messages and communications need to be clear and concise. Some evidence studying Air Traffic Control and pilot communication has shown using a grouped message format rather than a sequential message format can improve the effectivity of communication [18].

Information gathered from this study will be used to adjust and improve information display and participant workstation use derived from ongoing task analyses of various positions. Based on the above results, significant changes have already been implemented into the ongoing design of ROAM enhancing the workstation design, arrangement, and functionality for a GCSO. Further work should validate the information needs of the GCSO and investigate other future positions like a vertiport manager and airspace surveillance manager to provide information that helps meet their needs. It remains important to the evolution of ROAM to adapt to the needs of the user and their role in the command and control of vehicles from a remote operations center.

V. Extensibility of a Remote Vehicle Operations Center for UAM Research

The prototype remote vehicle operations center with its capabilities and impacts described within this paper is extensible to other research activities in AAM that seek to study a future airspace system that explores HAT-enabled *m:N* operations. Several entities in government, industry, and academia are currently conducting research in this domain. The development of a remote vehicle operations center such as ROAM provides the backbone necessary to conduct research into current and future domains while informing evolving aviation regulations. In its current form, the ROAM UAS Operations Center enables the maturation of technology and concepts in simulation and flight to support the continued development of new and emerging UAM and AAM operations and technologies. ROAM enables the full end-to-end hardware- and human-in-the-loop simulation testing with simulated sUAS, providing connections for an LVC environment. With ROAM, NASA researchers can leverage the established flow of simulation-to-flight and therefore lower the transfer risk of new ideas and technologies with this type of research and development environment.

A. Future Technical Development

With the first simulation study completed in the Fall of 2021 (Ref. [9], [14], and [25]), and a series of subsequent live vehicle operations having been conducted from ROAM (Ref. [15] and [26]), the evolutionary process of the facility continues. The systems that the ROAM UAS Operations Center connects into are part of an ever-evolving ecosystem, supporting the needs of researchers and flight operations for projects at NASA LaRC. As the need shifts within NASA projects and industry to command and control more vehicles from a remote location (i.e., BVLOS), additional information will be required to substitute for the information that is available to operators when controlling a vehicle under visual line of sight conditions. The following is a brief listing of areas of ongoing and future development that are connected to ROAM:

- Integrated Airspace Surveillance Display
- Voice Communication System for Operations Support
- Video Surveillance Source for Operations Support
- Vertiport Automation System / Vertiport Manager Role
- Weather Information System, Micro-Climate Sensors
- Integration into the NASA Internet of Things (IoT) Platform

At NASA LaRC, several simulation facilities and equipment capabilities exist that the ROAM UAS Operations Center could be connected to in the future, enabling a larger and more dynamic live, virtual, and constructive (LVC) environment. One such example that the NASA research team is currently exploring is a connection to the NASA UAM Flyer [27] as a crewed or uncrewed simulated vehicle that could be a part of the LVC environment and could be controlled by a GCSO within ROAM. A suite of these vehicles coupled with existing point-mass modeled vehicles and live-flight vehicles is a near-term technical development goal.

Near-term development plans in ROAM are focused on providing users with supplemental information to support initial multi-vehicle operations and more sophisticated onboard automation. Yet to achieve the level of scalability needed to enable mature AAM operations, a paradigm shift is required that will allow significantly fewer human operators to manage more increasingly autonomous vehicles (i.e., *m:N*). Here, the role of the human will need to change substantially such that responsibility for and authority over individual vehicles shifts from the human to the autonomous (or highly automated) vehicle systems. This shift will transform the human's role from *managing* multiple vehicles to *assisting* many more vehicles at a much larger scale [28]. This paradigm shift in vehicle management to enable these types of operations has been identified by NASA's T^3-RAM subproject as a critical area of research into human-autonomy teaming. Indeed, an overarching goal of ROAM is to provide a research testbed that can evolve to support this paradigm shift.

B. Potential Research Activities

A remote vehicle operations center like ROAM enables research activities that would be prohibited in a mature operations center, such as those that must routinely conduct daily operational activities with fixed versioning of workstation and software applications. A remote vehicle operations center like ROAM described within this paper can be used to conduct research into several specific areas of AAM, such as:

- **Technology Performance Studies.** New individual and pairings of AAM technologies and HAT concepts will be developed that will require a facility supporting RD&T environments. With ROAM, various technology performance studies and benefits analyses could be conducted to justify adoption and inform evolving aviation regulations.
- **Procedure Development.** By equipping select GCSOs within an operational scenario with one or more airspace services/technologies in a human-in-the-loop (HITL) study, procedures and interactions may be evaluated between the different roles of the operations center.
- **Human Factors Analyses.** By equipping select GCSOs and other roles in an operational scenario with one or more airspace services/technologies in a HITL study, human factors data can be collected and evaluated to address various research questions. Data gathered from these studies may include both objective metrics (e.g., eye tracking data) and subjective metrics (e.g., subjective workload, situation awareness, and human-automation trust) to determine how humans interact within a remote vehicle operations center.
- **Integrated Simulation Studies.** By connecting the capabilities described for ROAM with external simulations and resources, integrated air-ground simulation activities with realistic operational scenarios may be conducted. This type of activity presents a unique opportunity to not only evaluate a given technology's performance or the procedures used to operate it within the context of a facility like ROAM, but to evaluate the interaction of multiple users and their roles in the command and control of remote vehicles while assessing human-autonomy teaming concepts within the emerging AAM ecosystem.
- **Future Evolutions.** ROAM is part of an evolving ecosystem, supporting the needs of researchers and increasing the value of simulated and live flight operations. The design of ROAM supports the functional

transition from current field control to future remote operations and management of sUAS while supporting the exploration of HAT-enabled *m:N* operations. This type of facility will continue to evolve to support new user roles and responsibilities in AAM research.

VI. Conclusions

The NASA AAM-HDV AOA Simulation was conducted with support of a remote UAS operations center, ROAM. An initial human factors and usability assessment of ROAM during the AOA Simulation was conducted with emphasis on the GCSO position. The approach taken was largely inductive, and therefore only descriptive statistics and participant comments are provided. Initial results from AOA Simulation generated several recommendations to improve ROAM, shape future research directions, and produce potential hypotheses that may be tested in more controlled laboratory settings. The usability ratings by participants in AOA Simulation were generally high, reflecting a promising start for the facility in conducting command and control of vehicles from a remote location. Based on these findings, significant changes have already been implemented into the ongoing design of ROAM enhancing the workstation design, arrangement, and functionality for a GCSO. The ROAM UAS Operations Center has developed into a world-class RD&T environment that can support both the collection of human factors data and support multiple needs of researchers answering questions of today and tomorrow on AAM.

VII. References

[1] National Academies of Sciences, Engineering, and Medicine, "Advanced Aerial Mobility: A National Blueprint," The National Academies Press, Washington, DC, 2020.

[2] V. V. Aubuchon, K. E. Hashemi, R. J. Shively and J. M. Wishart, "Multi-Vehicle (m:N) Operations in the NAS - NASA's Research Plans," in *AIAA Aviation 2022 Forum*, Chicago, IL, 2022.

[3] Northeast UAS Airspace Integration Research Alliance (NUAIR), "High-Density Automated Vertiport Concept of Operations," Syracuse, NY, 2021.

[4] National Aeronautics and Space Administration, "High Density Vertiplex Subproject," 23 August 2021. [Online]. Available: https://www.nasa.gov/aeroresearch/programs/iasp/aam/hdv/description/.

[5] J. B. Holbrook, L. J. Prinzel III, E. T. Chancey, R. J. Shively, M. S. Feary, Q. V. Dao, M. G. Ballin and C. Teubert, "Enabling Urban Air Mobility: Human-Autonomy Teaming Research Challenges and Recommendations," in *AIAA Aviation 2020 Forum*, Virtual Meeting, 2020.

[6] E. T. Chancey, M. S. Politowicz and L. R. Le Vie, "Enabling Advanced Air Mobility Operations Through Appropriate Trust in Human-Autonomy Teaming: Foundational Research Approaches and Applications," in *AIAA SciTech 2021 Forum*, Virtual Meeting, 2021.

[7] M. S. Politowicz, E. T. Chancey and L. J. Glaab, "Effects of Autonomous sUAS Separation Methods on Subjective Workload, Situation Awareness, and Trust," in *AIAA SciTech 2021 Forum*, Virtual Meeting, 2021.

[8] J. Brown, "CERTAIN: City Environment Range Testing for Autonomous Integrated Navigation," NASA, Hampton, VA, 2016.

[9] L. J. Glaab, M. A. Johnson, R. G. McSwain, S. C. Geuther, Q. V. Dao and J. R. Homola, "The High Density Vertiplex Advanced Onboard Automation Overview," in *AIAA 2022 Digital Avionics Systems Conference (DASC)*, Portsmouth, VA, 2022.

[10] M. S. Politowicz, E. T. Chancey, B. K. Buck, J. R. Unverricht and B. J. Petty, "MPATH (Measuring Performance for Autonomy Teaming with Humans) Ground Control Station: Design Approach and Initial Usability Results," in *AIAA SciTech 2023 Forum*, National Harbor, MD, 2023.

[11] "QGC - QGroundControl - Drone Control," [Online]. Available: http://qgroundcontrol.com/. [Accessed October 2022].

[12] Tobii, "Tobii Pro Nano - tobii.com," Tobii, [Online]. Available: https://www.tobii.com/products/eye-trackers/screen-based/tobii-pro-nano. [Accessed October 2022].

[13] Tobii, "Tobii Pro Lab - tobii.com," Tobii, [Online]. Available: https://www.tobii.com/products/software/data-analysis-tools/tobii-pro-lab. [Accessed October 2022].

[14] J. R. Unverricht, E. T. Chancey, M. S. Politowicz, B. K. Buck and S. C. Geuther, "Eye Glance Behaviors of Ground Control Station Operators in a Simulated Urban Air Mobility Environment," in *AIAA 2022 Digital Avionics Systems Conference (DASC)*, Portsmouth, VA, 2022.

[15] J. R. Unverricht, M. S. Politowicz, E. T. Chancey, B. K. Buck, S. C. Geuther, K. M. Ballard and R. G. McSwain, "Where is the Human-in-the-Loop? Human Factors Analysis of Extended Visual Line of Sight Unmanned Aerial System Operations within a Remote Operations Environment," in *AIAA 2023 SciTech Forum*, National Harbor, MD, 2023.

[16] S. G. Hart and L. E. Staveland, "Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research," *Advances in Psychology,* vol. 52, pp. 139-183, 1988.

[17] R. M. Taylor, "Situational Awareness Rating Technique (SART): The Development of a Tool for Aircrew Systems Design," in *AGARD Conference Proceedings No. 478, Situational Awareness in Aerospace Operations*, Copenhagen, 1990.

[18] J. Nielsen, "Why You Only Need to Test with 5 Users," Nielsen Norman Group, 18 March 2000. [Online]. Available: https://www.nngroup.com/articles/why-you-only-need-to-test-with-5-users/. [Accessed 2022].

[19] J. Nielsen and T. K. Landauer, "A Mathematical Model of the Finding of Usability Problems," in *Proceedings of the INTERACT '93 and CHI '93 Conference on Human Factors in Computing Systems*, Amsterdam, 1993.

[20] J. R. Lewis, "Psychometric Evaluation of the Post-Study System Usability Questionnaire: The PSSUQ," in *Proceedings of the Human Factors Society Annual Meeting*, Los Angeles, CA, 1992.

[21] C. D. Wickens and C. M. Carswell, "The Proximity Compatibility Principle: Its Psychological Foundation and Relevance to Display Design," *Human Factors,* vol. 37, no. 3, pp. 473-494, 1995.

[22] R. A. Rensink, "Change Detection," *Annual Review of Psychology,* vol. 53, pp. 245-277, 2002.

[23] M. S. Wogalter, S. S. Godfrey, G. A. Fontenelle, D. R. Desaulniers, P. R. Rothstein and K. R. Laughery, "Effectiveness of Warnings," *Human Factors,* vol. 29, no. 5, pp. 599-612, 1987.

[24] O. V. Prinzo and D. G. Morrow, "Improving Pilot/Air Traffic Control Voice Communication in General Aviation," *The International Journal of Aviation Psychology,* vol. 12, no. 4, pp. 341-357, 2002.

[25] G. S. Hodell, Q. V. Dao, J. R. Homola, M. T. Goodyear, S. N. Kalush, S. Swaroop and J. Yoona, "Usability Evaluation of Fleet Management Interface for High Density Vertiplex Environments," in *AIAA 2022 Digital Avionics Systems Conference (DASC)*, Portsmouth, VA, 2022.

[26] M. S. Politowicz and R. G. McSwain, "Exploring Future Aviation Operations at NASA," in *PX4 Developer Summit 2022*, Austin, TX, 2022.

[27] E. C. Blount, R. W. Maddox, C. J. O'Connor and D. V. Wood, "Distributed Simulation Infrastructure for Researching Implementation of Evolving Concepts in the NAS," NASA/TM–2022-0004546, Hampton, VA, 2022.

[28] T. Sato, M. S. Politowicz, S. Islam, E. T. Chancey and Y. Yamani, "Attentional Considerations in Advanced Air Mobility Operations: Control, Manage, or Assist?," in *HFES 66th International Annual Meeting*, Atlanta, GA, 2022.