Fourteenth USA/Europe Air Traffic Management Research and Development Seminar (ATM2021)

Management of Operations under Visual Flight Rules in UTM for Disaster Response Missions

Adriana Andreeva-Mori, Kohji Ohga,
Keiji Kobayashi, Yoshinori Okuno
Japan Aerospace Exploration Agency (JAXA)
Mitaka, Tokyo, 181-0015, Japan

Jeffrey Homola, Marcus Johnson, Parimal Kopardekar
NASA Ames Research Center
Moffett Field, CA, 94035, United States of America

***Abstract*—The disaster response domain has experienced an increased focus in recent years due to the rise in number and scale of events, lessons learned from past experience, and emerging technologies that make possible a more coordinated and effective response. As part of this focus, JAXA and NASA have been collaborating on the integration of manned and unmanned aircraft in support of disaster response operations through integrated testing of their respective mission planning and optimization system (Disaster Relief Aircraft Information Sharing Network, or D-NET) and an automated UAS traffic management system (e.g., UTM). In 2018, JAXA and NASA jointly participated in a large-scale disaster drill in Japan where the integration of systems was successfully demonstrated through real-time data exchanges, visualization, and decision making as part of the coordinated airspace management of a manned helicopter in VFR conditions and unmanned small UAS operating in common areas. This work details a flight test consisting of two flights that were conducted December 2019 near the Chofu Aerodrome in Tokyo, which focused on the evaluation of pilots operating under Visual Flight Rules (VFR) communicating through D-NET and sharing intent and position information within UTM. This work contributes to defining the necessary requirements for digital coordination between manned and unmanned operations. UTM requires the use of operation volumes, which are spatial and temporal volumes that encompass UAS flight trajectories and account for technical performance errors and deviations due to disturbances (e.g., wind). A series of flights, representing different missions, used landmark-based operation volumes and conformance of the aircraft to those operation volumes were tracked within UTM. Experienced disaster response helicopter pilots provided insight on the development of the operation plans and their usability during disaster response operations. Results from the flight test supported the suggested benefits of using landmarks for planning and positional awareness and highlighted the need for future research in advanced visualization capabilities to support operations that consider both system constraints and flight deck/airspace management interaction.**

Keywords- disaster response, airspace management, VFR, landmark, operation volume

I. INTRODUCTION

During disasters damaged infrastructure often prevents ground vehicles from accessing geographic areas. To facilitate an effective response, disaster operations often rely on aircraft for reconnaissance, search and rescue (SAR), and supply delivery missions. Large-scale disasters require the coordination of multiple helicopters and ground-based resources for safe and efficient response operations. Until recently, only manned aircraft needed to be coordinated for mission assignments and flight planning. Despite emerging research on the topic [1], this process can prove onerous given that few decision-support systems have been developed and implemented in practice. The existing process coordinating mission assignments and flight planning limits illustrates a challenge in increasing the number of missions and integrating new types of technologies, such as unmanned aircraft systems (UAS). Recent technology advances have led to increasing use of UAS in post-disaster relief operations to support or replace manned operations for: reconnaissance, search and rescue, and supply deliveries [2]. Advancements in UAS technology have allowed for reduced operation costs, quicker mission deployments, and expanded mission capability. These benefits have promoted the introduction of UAS in disaster response operations, but challenges remain preventing the widespread use of UAS to support disaster response. This work proposes the use of mission planning and traffic management technology to address the challenge of coordination between manned aircraft and UAS during a disaster response operation. As UAS and manned aircraft operate in the same airspace, the need for information sharing, such as current position and flight path intent, become critical for maintaining safe operations during disaster response [3]. The need for coordination is heightened during phases of the relief operations that require various types of aircraft to operate in close proximity of each other within a target area. For example, during a SAR operation a UAS will perform a mission to search for survivors, which is subsequently followed by a rescue mission conducted from a manned helicopter. Both the UAS and the helicopter will need to share the airspace in order to be most efficient at the SAR operation. Given the diversity of missions and operational constraints during a disaster response operation the ability to segregate manned aircraft and UAS within the airspace is more challenging than during nominal operations.

This work investigates concepts for defining and sharing operation volumes to describe the intended flight plan of helicopter missions operating under VFR supporting disaster response missions. These operation volumes will also be communicated with the UAS Traffic Management (UTM) system to enable strategic coordination between manned and unmanned aircraft. This work describes the

1. Design of 4D operation volumes to match the characteristics of VFR helicopter operations, based on feedback obtained from prior work, and
2. A flight test consisting of two flights using a JAXA helicopter and experienced disaster response pilots conducted in December 2019 near Tokyo that mimics disaster response missions and evaluates the applicability and usability of operation volumes.

Section II of this paper provides a background description of manned and unmanned operations, mission planning, and traffic management systems. Section III describes the proposed operation volume definition based on missions, and Section IV describes how data is communicated between the pilot and UTM. Section V describes the flight test setup and results, and Section VI provides concluding remarks.

II. BACKGROUND

A. *Manned and Unmanned Disaster Response Operations*

The response to a disaster will often involve a wide variety of aircraft assets from different organizations such as the military, firefighting agencies, medical agencies, and the media. During disaster response operations in the United States and Japan, most aircraft operate under visual flight rules (VFR), which requires the pilot to see and avoid other aircraft and operate under visual meteorological conditions (VMC) to avoid collisions with terrain and ground obstacles. The need for VFR operations, as opposed to operating under instrument flight rules (IFR), is due to the fact that a large portion of disaster response aircraft assets are helicopters that are not properly equipped for IFR operations and disaster response involves uncertainties during the mission that require the pilot to make on-the-fly assessments and course corrections to support the operation. To this end, operations under VFR have a higher degree of flexibility to adapt to the needs of the response mission and can more easily deviate from a flight plan than operations under IFR. In addition, operations under VFR benefit from the pilots' ability to see and avoid other aircraft, which can support more aircraft operating in a target area. However, see and avoid can be problematic to the coordination between manned aircraft and UAS. Due to their size, visual acquisition of sUAS can be difficult for pilots of helicopters [4].

In contrast, UAS can conduct operations using see and avoid when the UAS is within visual line of sight (VLOS) of the UAS operator. However, beyond visual line of sight (BVLOS) operations are conducted primarily by the use of instruments but may not be required to operate under IFR. According to the FAA UAS Traffic Management (UTM) Concept of Operations (ConOps) [5], UAS operating below 400 ft can provide an operation volume that declares the area and times of intended operation. UTM uses the operation volume to support strategically deconflicting an intended operation with other operations in the airspace.

B. *UAS Traffic Management (UTM)*

The objectives of UTM are to enable a safe and scalable approach to support the use of small UAS operations at low altitude; providing flexibility in use of the airspace where possible and structure where necessary. The integration of public safety entities and their operations into the UTM ecosystem has been a focus of research throughout the NASA Technical Capability Level (TCL) development and demonstrations. The UTM technology development and assessments focused on a common situation awareness display, airspace deconfliction, operation prioritization, and coordination of dynamic changes to operation intent. These capabilities support the extension of the UTM concept and technologies to disaster response efforts and provide the necessary coordination and situational awareness to facilitate a more efficient response.

Standards development is underway for different aspects of UAS operations and UTM. However, currently there exists no agreed upon standards for manned-unmanned aircraft coordination. Disaster response aircraft operations offer a microcosm that could represent a collaborative future airspace environment. Lessons learned from technology development and integration of manned and UAS aircraft in disaster response area can inform future UAS and UTM standards development in organizations like ASTM International and the International Organization for Standardization (ISO).

C. *Disaster Relief Aircraft Information Sharing Network (D-NET)*

As a means to increase aircraft safety and mission efficiency during disaster response, the Japan Aerospace Exploration Agency (JAXA) has been developing the Disaster Relief Aircraft Information Sharing Network (D-NET). The D-NET system assists in the collection and sharing of disaster information through the integrated operation of aircraft, such as helicopters, UAS, and satellites [6]. The objective of D-NET is to efficiently acquire data from multiple sources, analyze the data, and provide an optimal resource allocation and flight plan trajectories, which can be integrated in the planning and execution of rescue and response operations. D-NET is designed as a portable system for aircraft operation management in the immediate aftermath of a large-scale disaster. The D-NET functions and their interactions are shown in Figure 1.

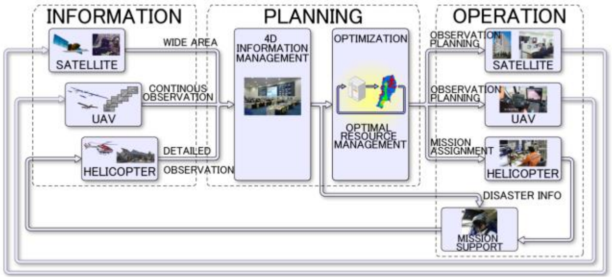

Figure 1. D-NET conceptual architecture

The system consists of three primary functions: 1) data/information acquisition, 2) planning optimization, and 3) operation execution. D-NET optimizes based on aircraft performance and assigns missions to each aircraft. Similar to existing disaster relief operations, helicopters are responsible for providing detailed information on the damage levels and evacuees, transportation missions for endangered persons, and the delivery of medicines and other goods. Depending on the onboard equipage, helicopters can also transport patients from a hospital which has been stricken by the disaster to other safe areas/hospitals.

In contrast, satellites can provide imagery over a wide disaster area even in the event of bad weather. Satellite imagery can be used, for example, to identify flooded areas [7], landslides, and bridge damage. D-NET uses the data provided by satellite imagery to aid disaster management authorities in their evaluation of the overall damages and to generate optimal manned aircraft assignment and trajectories.

More recently, UAS have been used in D-NET during disaster response operations to monitor specific areas of interest [8]. D-NET assigns data acquisition missions to UAS in order to spare resources from the manned aircraft fleet, which then allows for more helicopters to be dedicated to critical rescue missions.

The development of the D-NET system requirements and functionality was based on feedback and collaboration with responders and coordinators that currently support disaster response operations. As a result, D-NET's onboard mission support system is currently installed on all firefighter helicopters in Japan. All D-NET's functionality and capability has been tested in large-scale disaster drills and numerous flight tests involving pilots with disaster relief experience.

D. *Prior D-NET and UTM Integrated Flight Testing*

Although UAS have been used in D-NET, a need was identified to further increase safety and promote the greater application of UAS to disaster response. To that end, a collaboration was established in 2016 between JAXA and NASA to conduct research investigating the integration of the D-NET and UTM systems [9]. In 2018 a joint flight test was conducted in the Ehime Prefecture, Japan, that was part of a national large-scale disaster drill, which highlighted the importance of heterogeneous manned and unmanned operations in disaster response. This test also revealed several challenges of the current operational concepts and technologies. One identified challenge was a discrepancy between the interpretation of operation volumes within UTM. As a means to provide safe separation between operations, UTM requires the definition of spatial and temporal volumes that encompass UAS flight trajectories and account for technical performance errors and deviations due to disturbances (e.g., wind) [5]. Given that most UAS operate by following pre-programmed waypoints, the operation volumes can be relatively small based on the known performance of the UAS. In contrast, when assigning volumes to a piloted operation under VFR, the volumes need to be sufficiently large to account for non-waypoint operations but small enough to provide ease of visualization for the pilot. It was evident through the testing that the notion of declaring intent and monitoring conformance needs to be consistent with the expected behavior of the operation. The sharing of intent and strategic deconfliction of intended operations provides a suitable means for reducing the required performance for tactical conflict management mitigations. However, to be effective, the defined operation volumes need to be flexible and easily understood to the airspace users.

III. OPERATION VOLUME CONCEPT AND DESIGN

This research proposes the use of operation volumes within UTM to define intent for helicopter operations analogous to those used by small UAS. In this section, the concept of operation volumes within UTM is presented followed by a description of the initial helicopter operation volumes proposed and flight tested during a Disaster Drill in Japan in October 2018. The remainder of this section will focus on helicopter operation volumes that were designed to meet the requirements of manned VFR flights based on established disaster response practices, established UAS volume designs used in UTM, and feedback from the two experienced pilots during the disaster drill.

A. *UAS Operation Volumes in UTM*

In traditional air traffic management, flight plans are submitted prior to each flight to the service provider to inform them of the flight intentions. In UTM, this intent is expressed in the form of an operation plan [5]. According to the UTM ConOps, the operation plan "should indicate the volume of airspace within which the operation is expected to occur, the times and locations of the key events associated with the operation, including launch, recovery, and any other information deemed important (e.g., segmentation of the operation trajectory by time)." UTM uses operation volumes to confirm there are no spatial and temporal overlaps with other airspace constraints and operation volumes from other UAS operators in the airspace. For this disaster response research, it was assumed UTM would not allow operation volumes to intersect in time and space. Therefore, the operation volume represented an airspace "reservation" that ensured that no pre-departure conflicts would exist. Figure 2 presents an example of two operations within UTM. The operation on the left is a singular volume operation, while the operation on the right is a multi-segmented operation volume where each segment has a beginning and end time.

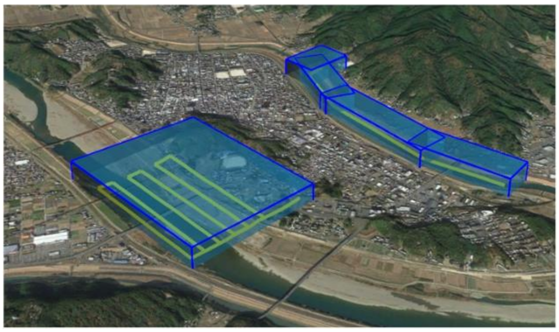

Figure 2. Sample UAS operation volumes

B. *Helicopter Operation Volumes at Ehime Prefecture Disaster Drill Flight Test*

During the flight test in Ehime, Japan in October 2018, JAXA's experimental helicopter operated in proximity to UAS in the same airspace. The helicopter's VFR flight was represented within UTM as a planned mission with an assigned operation volume similar to those of UAS operations. Post-flight interviews with the pilots suggested that the pre-designed operation volume sufficiently covered the airspace occupied by the helicopter during the mission, but the pilot could not easily confirm the relative position of the aircraft with respect to the volume boundaries since the only visual reference available was a static image of the geographic operation volume provided in a pre-flight pamphlet. Flight track data from the flight test also indicated that the pre-defined operation volume could be reduced for more efficient airspace usage [3].

C. *VFR Flight Plans*

In Japan, it is a common practice that prior to each VFR flight the pilots file a flight plan containing information on the aircraft identification, departure and arrival airports and times, flight route, cruise altitude, speed, etc. If the aircraft is not at its arrival destination and has not contacted ATC 20 minutes after the arrival time noted in the flight plan, search and rescue operations will be initiated. Therefore, the flight times in the flight plan usually reflect the pilot's intentions accurately. However, given the dynamic nature of disaster response missions, flight plans filed for response missions include a considerable time margin.

The flight plans filed for the purposes of the December 2019 flight tests discussed in this paper also followed similar best practices. The helicopter took off and landed at Chofu Aerodrome, Tokyo (see Figure 3) and conducted its mission in Japan's Kanto/Koshinetsu civil flight test area.

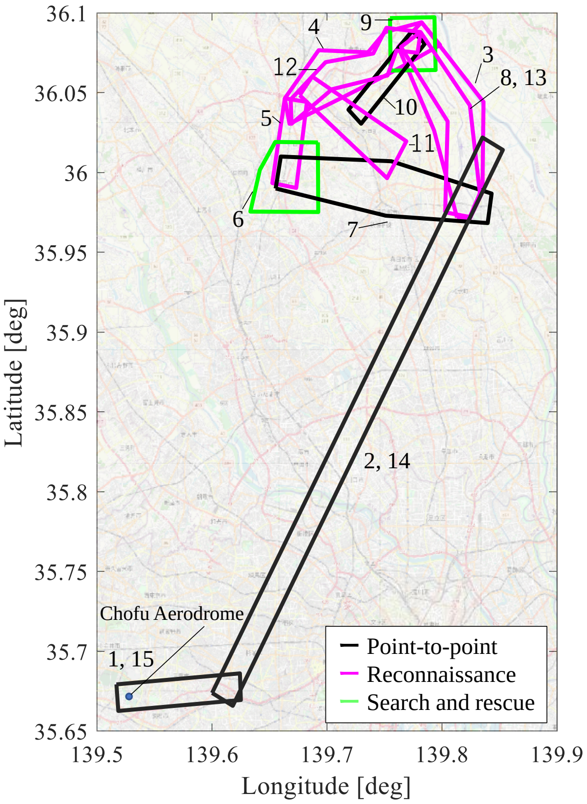

Figure 3 Operation volumes categorized by segment purpose

For operations under VFR in Japan, the cruise altitude does not need to be specified as long as it is less than 3000 ft above ground or water, see AIP ref ENR 1.1-2 [10]. While in flight, the aircraft has to maintain a minimum safety altitude as defined by Article 81 of the Civil Aeronautics Act [11] and a minimum safety altitude 500 ft above ground or water surface, apart from densely populated areas. Therefore, a VFR flight with unspecified cruise altitude can fly between approximately 500 ft and 3000 ft.

D. *Operation Volume Design of Disaster Relief Helicopter Missions*

Discussions with pilots and dispatchers after the Ehime Prefecture Disaster Drill in 2018 suggested that the operation volume should depend on the mission type. In this research we focused on three mission types in the design of volumes: 1) Point-to-point movement (transfer), 2) Reconnaissance, and 3) Search and rescue (SAR).

1) Point-to-point movement: Point-to-point flight segments can be controlled either manually or by the helicopter's autopilot. Manual control is preferred when the target point is near and is visible (up to 2.5 nmi ahead on a clear day). Pilots often use major landmarks such as mountain peaks (e.g., Mt. Fuji, Mt.Tsukuba, etc.) when the target is relatively far and switch to smaller landmarks (e.g., towers, factory chimneys, etc.) as they get closer. The pilot may use the flight director to aid in navigation as well. Control by an autopilot requires a pre-programmed set of waypoints and is therefore often used in the initial and final segments of the flight, like the connecting segments between Chofu Aerodrome and the KK4-4 airspace shown in Figure 3 by volumes outlined in black. Few deviations from the route are expected during point-to-point operations, so the lateral allowance of the operation volume often is relatively small. The operation volume within UTM for both manual and autopilot operations considers the intended flight path of the aircraft as the centerline within a multi-segmented volume. The width of the operation volume was 0.5 nm lateral from the flight path centerline, based on input from the pilots of expected flight technical error. Once the helicopter takes off and reaches its planned cruise altitude, minimal altitude deviations are expected, so the operation volume was constrained to a geometric altitude between 0 ft and 5000 ft. For each segment of the operation volumes within UTM, a start ($time_{begin}$) and end ($time_{end}$) time must be defined. The time intervals for each segment of the point-to-point movement can be calculated based on the average cruise speed and distance between two waypoints. To account for early take-off, a buffer of 10 min is added to the start time of the first flight segment and to account for any departure and flight delays a buffer of 10 min is added last flight segment. For this December 2019 flight test the ability to dynamically update the operation volume times due to a delayed departure or arrival was not supported.

2) Reconnaissance: Reconnaissance missions are essential for fast and efficient disaster response. Right after the disaster, no information on the damage and rescue needs is available. In particular, information on ground infrastructure (e.g., road and railroad conditions, bridges, etc.) and the extent of flooding and landslides are crucial for efficient and timely resource and personnel allocation. Flights performing reconnaissance missions have more uncertainty regarding the intended flight path and, therefore, are not as static as point-to-point movement operations. During the flight, detailed observation by the pilot might require route deviations and longer time to examine the damage and confirm the number of evacuees. Unlike point-to-point movement, the flight control is manual only. According to pre-flight interviews with disaster responders, the pilot often navigates by tracking landmarks such as rivers, bullet train lines, and highways. When the pilot in the right seat is in control, they will fly so that the landmark is seen on their right side. Flying along a landmark offers a high level of stable positional awareness. Therefore, for reconnaissance missions, operation volumes were defined to follow geographic landmarks. As UAS do not typically leverage visual cues for navigation, the definition of landmark-based operation volumes for flights under VFR is novel within the UTM concept. Ideally, the reconnaissance mission volumes can support very complicated shapes, but in our initial designs we opted for simplified polygons defined by no more than 10 vertices. The volume geometry is defined as polygons with a center line relative to the landmark and a buffer of approximately 0.5 nm on each side. The effective times (pre-flight estimation) for the volume is calculated based on average reconnaissance speed typical for such aircraft and missions with a buffer of 10 min added.

3) Search and rescue: The third disaster relief mission modeled is the search and rescue (SAR) of victims. The search is usually initiated after information on the victim's approximate location is received at the disaster operation center. Therefore, a typical flight pattern consists of circling around the expected victim's location gradually expanding the radius until the victim is visually identified. The rescue depends on the terrain and helicopter equipage- the helicopter can either land to pick up the victim or send rescue personnel to hoist the victim if landing is not safe. During hoist, the helicopter hovers over the victim's location. Once the victim is on board, they are transported to a safe location; often to a nearby evacuation point or field. Due to the minimum safety altitude constraints prohibiting landing over the rescue site during the flight test, the rescue is modeled by adding a hovering segment to the trajectory. The lateral part of the operation volume for SAR is then designed as a square 1 nm on each side, and no additional altitude constraints are imposed. Based on pilot input, we assume SAR can be completed in 10 min.

E. Flight test scenario and operation volumes

Two flights were conducted to verify the volume design concepts presented above. Each flight consisted of 15 volumes: 6 point-to-point movement operations (including transport of evacuees), 7 reconnaissance operations and 2 search and rescue operations.

IV. DATA FLOW CONFIGURATION

The flight test configuration shown in Figure 4 depicts the interactions between the aircraft, D-NET systems, and the UTM system. In this flight test, the helicopter's operation volumes were designed manually as part of the D-NET operation planning process. In future research, this task will be assigned to D-NET's optimizer, responsible for resource allocation, mission assignment, and route generation. Prior to takeoff, the operation volumes were sent from JAXA's D-NET system to NASA's UTM system as an operation plan using translator software, denoted as DLinkUTM, which enables real-time communication between D-NET and UTM. DLinkUTM was developed and tested in the disaster drill tests in 2018 [3]. Once the operation plan was received, the UTM system verified that the operation volumes were not in conflict with other operations and airspace constraints. If no conflicts were identified, the operation state transitioned from Proposed to Accepted. The UTM users, including the helicopter crew, were notified of the operation state transition via messages from the UTM system. Subsequent state transitions included Active, Non-Conforming and Rogue, and Closed.

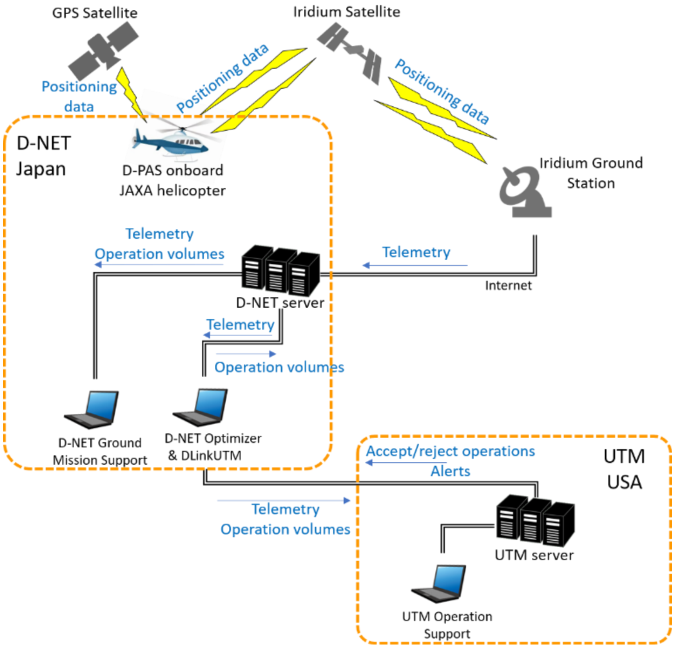

Figure 4. Flight test configuration and basic information flow

In order to monitor the position of the helicopter from the ground and relay the position information to UTM, D-NET's onboard mission support system (D-PAS) was used. D-PAS is a fully portable system and can be brought onboard the aircraft as needed. It consists of three main components: a satellite transmission component, a digital antenna, and a touch-screen display that enables manual input on behalf of the operator onboard the helicopter as shown in Figure 5. D-PAS enabled position data sharing between the aircraft and the ground. In flight, once the helicopter telemetry was received by the D-NET servers through DLinkUTM, it was sent to UTM, which monitored the aircraft's conformance to its operation volumes and issued alerts to the helicopter crew and ground personnel as necessary. The position of the helicopter was also tracked by D-NET's ground personnel via the ground mission support system, which included information on operation volumes obtained through the D-NET server. The above data flow configuration allowed for real-time communication among all participants with minimal observed latencies, highlighting the global applicability of the system architecture as tested. Further details on the initial architecture and overall concept of operations including both manned and unmanned aircraft can be found in the authors' past work [8].

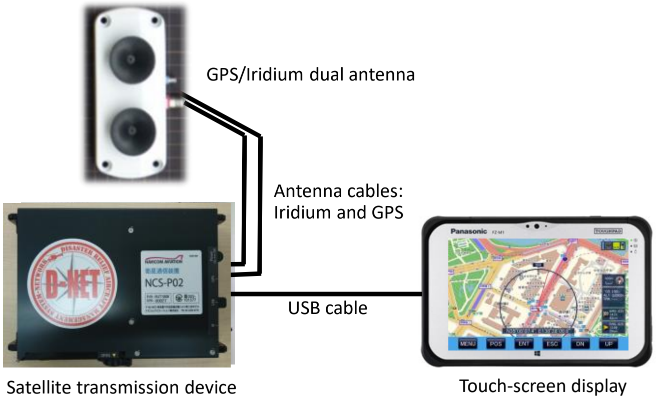

Figure 5. D-NET onboard mission support system (D-PAS) components

V. FLIGHT TEST

In December 2019, a live flight test was conducted in Japan to test the pilot-informed, landmark-based, mission-oriented approach to operation volume design and the information sharing of associated operations under VFR in a D-NET/UTM integrated environment. The test involved two sorties of a manned helicopter that flew representative disaster response missions while adhering to the operation volumes and tracked via supporting D-NET and UTM systems.

A. *Test Setup and Locations*

The flight test was supported by multiple personnel across two main locations: D-NET based in Tokyo, Japan, and UTM based at NASA Ames Research Center, USA.

The flight itself took place in the Tokyo vicinity where D-NET's team was located. The aircraft used in the flight test was JAXA's research helicopter [12] BK117 C-2, shown in Figure 6. The helicopter has an 8 person capacity (2 crew and 6 passengers), but in this flight test 4 personnel were onboard the aircraft: 2 crew and 2 researchers. The pilots and researchers were the same for both flights. The main pilot was a veteran with more than 3500 hours flight experience with Japan Maritime Self-Defense Forces, Sendai-shi Fire Fighting Fleet and JAXA. The co-pilot had several years of experience as police helicopter and disaster response helicopter pilot. The main pilot was always flying the aircraft, while the co-pilot was looking at the flight booklet and providing verbal assistance. The test included two pilots to model realistically real disaster response operations. Real time positioning data was transmitted via D-PAS through the dual antenna attached to the front shield. The transmitter was secured on the floor and the display was in the hands of a researcher. Apart from the D-PAS transmitted telemetry, positioning data from the aircraft measurement system was also available for post-event analysis. The helicopter took off and landed at Chofu Aerodrome in Tokyo.

Another team of researchers supporting D-NET's ground-based system was on station at JAXA's Chofu Aerodrome Research Center, where flight plan submissions from the D-NET to UTM systems were performed and the progress of the flight was monitored. A third team was located at NASA Ames Research Center in California at the Airspace Operations Laboratory. The team consisted of NASA researchers, engineers, and systems administrators that monitored the test remotely through visualizations from the UTM data exchanges as well as communications with the teams in Japan.

Figure 6. JAXA's BK117 C2 research helicopter shortly before takeoff at Chofu Aerodrome on the first day of the flight test

B. *Flight Preparation*

As mentioned in Section IIIC, the main part of the flight that simulated disaster response missions took place in civil flight test area Kanto/Koshinetsu Area 4-4 (KK4-4). The test area is located approximately 27 nm away from the take-off airfield. The flight portion from Chofu Aerodrome to KK4-4 and back was also used to simulate point-to-point movement (transit) (see Section IIID1). Once in KK4-4, each mission the helicopter conducted was in relation to a specific operation volume (i.e., one mission per volume). Each volume was first defined by a polygon with 4 to 10 vertices. Pre-flight estimates of volume entry and exit times were determined based on discussions with the pilots. The times accounted for average mission speed and distance to be covered, mission time including time buffers to accommodate any uncertainties, and additional information on auxiliary waypoints that might be used by the crew. The crew was advised to comply strictly with the buffered entry and exit times for each volume segment. The temporal buffers were defined sufficiently large to account for uncertainties during the operation.

To simulate real world disaster recovery operations, the crew was assigned detailed missions for some flight operation volumes in advance. For example, a mission such as, "Confirm Hoshubana Bridge has not collapsed," and related details were explained at the pre-flight meeting. Additional missions were given to the crew by a researcher onboard the helicopter during the flight without prior announcement. The operation volume information was given to the crew on paper, summarized in a flight booklet. This booklet consisted of the entire flight and associated volumes, a summary of the entry and exit times for all 15 volumes, and information on each individual volume. The pilots were provided information on the mission type associated with each operation volume, the entry and exit waypoints and their coordinates, flight time estimates, and buffer times submitted to UTM.

C. *Flight Test Results*

For the primary data collection flight, the test helicopter took off from Chofu Aerodrome at 12:55 JST and landed at 14:55 JST without incident. Prior to takeoff, the helicopter's flight plan, characterized by the 15-segment operation volumes, was submitted to UTM as an operations plan via DLinkUTM and ACCEPTED at 12:41 JST. Once accepted, the operation volumes, shown in blue (Figure 8), and the helicopter's current position, shown as a brown arrow, were visible on D-NET's Ground Mission Support System in Japan and to the UTM team in the USA on specialized displays.

While in flight, real-time monitoring of the helicopter's position was based on data from D-NET's onboard mission support system (D-PAS) and provided through DLinkUTM to UTM. Conformance monitoring of the submitted position updates relative to the operation volumes was performed by UTM throughout the flight. Helicopter positioning data transmission from D-NET to UTM was initiated at 12:45 JST, which changed the flight's operation state to ACTIVE. An item to note is that position updates transmitted by D-PAS were available once every 20 seconds. However, because the UTM system required more frequent position reports at once per second, the same position was sent from D-NET to UTM until the next updated position report was available.

The flight status remained ACTIVE until 13:49 JST when it became NON-CONFORMING, indicating temporal or spatial violation with the operation volume. After 31 s in the NON-CONFORMING state, the operation state turned to ROGUE at 13:50:20, which implied the flight was not conforming to its plan as expected. In the implementation of UTM at the time of this test, the ROGUE operation state represented a significant deviation from the intended operation plan and was a terminal operation state. Therefore, a transition back to ACTIVE was not possible after the first instance. However, positions continued to be sent to UTM for the entirety of the flight until the operation was CLOSED at 15:01 JST, after landing at Chofu Aerodrome was confirmed.

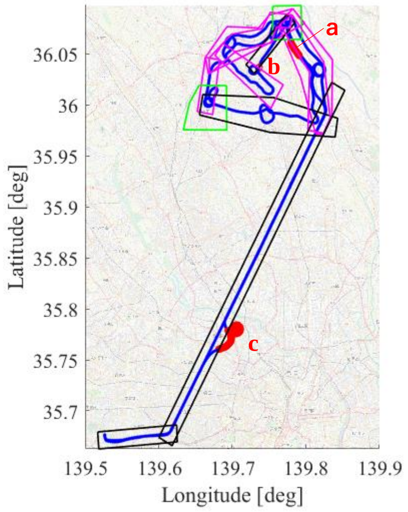

Figure 7. Flight path of helicopter as flown relative of operation volumes

In total, the helicopter went outside of its operation volume on three occasions: a) initially when performing a reconnaissance mission in operation volume segment 8 where it was non-conforming at 13:49 JST for 55 s and subsequently transitioned to ROGUE, b) when leaving operation volume segment 10 and entering segment 11 at 13:58 JST where the vehicle was outside of the expected volume for 2 s, and c) in operation volume segment 14 where the helicopter was outside of the volume bounds at 14:37 JST and returned 190 s later. These are referred to as Violations a, b and c in Figure 10. The helicopter's positions with respect to the operation volumes throughout the flight are shown in Figure 11. The blue dots indicate the helicopter was flying in conformance within the expected active 4D operation volume. The red dots show the positions when the helicopter was not conforming to its flight volume. The position data used for this analysis was obtained by the onboard aircraft measurement system. A more detailed description of each observed violation follows.

Violation a (operation volume segment 8), shown in Figure 8, occurred during the reconnaissance mission along the river in which the pilot confirmed their relative location to the river visually. The main pilot was seated in the right seat and flew the helicopter such that the river was always visible from the lower right window for easy reference as depicted in Figure 9.

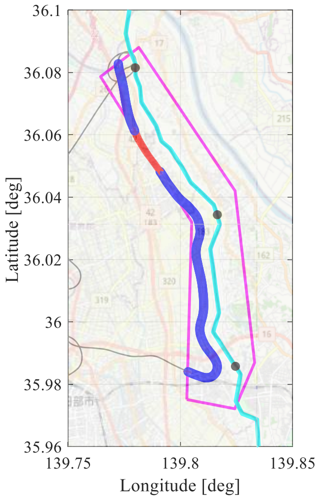

Figure 8. Breach of volume 8 by helicopter

In operation volume segment 8, the helicopter was flying north, so the entire trajectory shifted to the west along the river. The distance between the helicopter and the river is shown in Figure 10. The blue line shows the distance between the vehicle and the river (the portion of the non-conforming flight is shown in ochre), the magenta line shows the distance between the volume edge and the river and the dotted black line shows the 0.5nm threshold proposed as a threshold by the pilot according to their flight experience. The distance between the helicopter and the river varied between 0.28 nm and 0.46 nm, so even when it was non-conforming, it was within the 0.5 nm threshold. Therefore, had the volume edges been designed to be at least 0.5 nm at every point, the flight might have stayed conforming. This discrepancy in the volume definition and the visual tracking caused the eventual ROGUE operation state. However, it also stressed the importance of real-time situational awareness for volume compliance.

Violation b occurred when the flight was leaving operation volume segment 10 and entering segment 11 where the helicopter left the planned operation volume for 2 s. This violation was caused when the aircraft changed its heading right at the border of two nearly perpendicular volumes.

Figure 9. Pilot use of river as visual reference for volume boundary

Violation c in volume 14 occurred due to an unplanned reconnaissance mission which interrupted the point-to-point movement originally considered when designing the volume. Such unexpected mission changes could only be adopted by real-time operation modifications. This capability was tested in a past flight test, part of the large-scale disaster drill in Ehime Prefecture in October 2018 [3] but was not explicitly included in the scope of the current flight test.

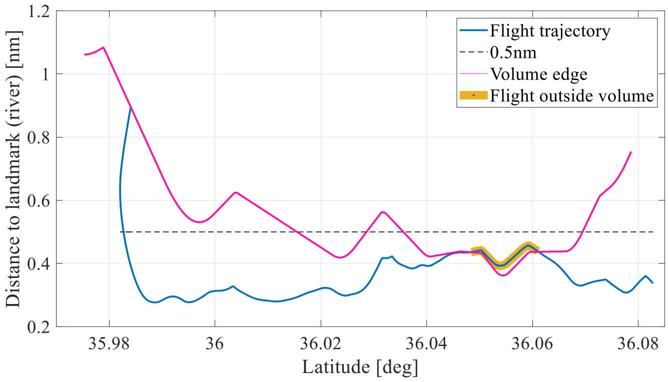

Figure 10. Analysis of flight trajectory relative to operation volume bounds for Violation a

Use of airspace was assessed by extracting the submitted begin and end times for each operation volume and plotting the times in which positions were reported within each volume, as shown in Figure 11. The horizontal axis shows the time in JST and the vertical axis shows the volume number. For each volume, the pre-flight estimate of the time within each volume (basic flight time) is shown in a bold black line, and the volume begin and end times submitted to UTM are shown as a thin (non-bold) black line. Note that the pre-flight estimated basic flight times do not overlap (i.e., they are sequential), but that the beginning and end times of operation volumes partially overlapped. The temporal overlap of volumes was by design to allow for flexibility and uncertainty in the transition between volume segments. Actual positions within each volume geography are shown in blue when the flight was conforming and red when the flight was in a spatial violation of the assigned volume.

As discussed, there were three distinct instances in which the helicopter breached the outer boundary of its operation volume. In the first instance (Violation a) of the helicopter flying outside of its volume, the UTM system transitioned the operation from an Active state, in which it was in conformance with its submitted plan, to a Non-conforming, and then Rogue state upon receiving a position update located outside of the operation volume's geographic bounds. According to the UTM concept at the time of these flights, the Rogue state was an end or terminal state that was not recoverable (i.e., the operation was unable to transition back to a conformant Active state). With respect to the entirety of the flight, the timing of the first violation resulted in nearly 50% of the flight spent in a ROGUE state in which the aircraft could still be tracked but conformance monitoring to the intended plan and the ability to update the operation plan were no longer available. However, with the exception of the unplanned reconnaissance mission on the return leg, the vehicle was only outside of volume bounds for very brief moments-on the order of seconds. Given the dynamic nature of disaster response situations, flexibility and an accurate, current common operating picture are needed features for operators and response managers. While perhaps appropriate for non-emergency UTM situations, the strict constraints imposed by a terminal Rogue state on operations within the UTM/D-NET systems during a disaster response mission are potentially overly restrictive and counter to the needs for flexibility and synchronous airspace and asset state situation awareness. Therefore, with the exception of Closed, the application of terminal states in UTM-supported disaster response missions may require an exemption where operators are able to return to an Active state for continued conformance monitoring and ability to update operational intent.

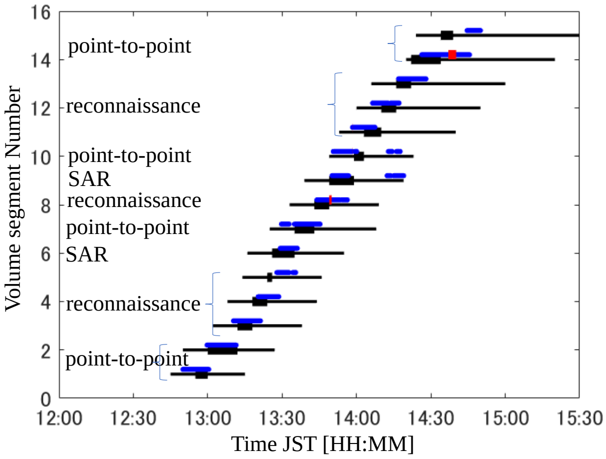

Figure 11. Positions within submitted operation volumes

One contributing factor that impacted the pilot's ability to maintain conformance to their operation volumes was the situation awareness available to them to mitigation deviations from their intended flight path. Based on the definition of the operation volume segments during various phases of the flight the aircraft occupied multiple segments simultaneously, however each segment had different geographic and spatial constraints. This is depicted in Figure 11, where at time 13:30 JST, the aircraft position, denoted in blue, occupied operation volume segments 5, 6, and 7, which corresponded to different phases of the operation. These operation volume segments, denoted in black, all have different begin and end times as well as spatial boundaries. Post-flight feedback from the pilots indicated that these overlaps caused confusion as to which spatial and temporal bounds to adhere to during particular phases of the operation. For this test, the pilots planned a sequential transition through volumes. However, when delays or deviations from operation intent occur in actual missions, the pilots will need to rely on tools from UTM and D-NET to provide situation awareness of their operational bounds. Future research should consider effective display guidance to inform pilots of their spatial and temporal conformance boundaries in real time.

Disaster response includes many uncertainties in the mission goal and trajectories. A reconnaissance or transfer mission, for example, can be temporally interrupted by a detailed search. In volume 3, when the helicopter was flying along the river conducting a reconnaissance mission, the crew was asked to confirm the status of a building near one of the bridges. In order to do so, the pilot executed a turn similar to a circular holding pattern, thus taking extra space and time. Even though this additional maneuver did not breach the volume geography, the aircraft stayed in the volume longer than originally planned. In volume 14, the aircraft diverted from the planned route and did not comply with its operation volume (Violation c), which caused both the operation violation and longer flight time. Alternatively, some SAR missions might be completed sooner than expected (see, for example, volume 9). Such in-flight mission modifications can be present in UAS operations as well, in case of emergency or technical failures, for instance, but generally speaking UAS tends to follow their flight plan. Manned aircraft operating in low-altitude airspace, on the other hand, often fly VFR and as such have more unpredictive flight paths. This is true even more in disaster response, when uncertainties in the environment require the pilot to adapt the flight path in order to complete their assigned mission, which by itself changes dynamically. Therefore, the ability to update the operation volume while in flight is very important. A capability allowing the crew onboard the aircraft to request swift changes to their operation volume is a prerequisite for efficient flight management and coordination in disaster response.

VI. PILOT DEBRIEF AND RECOMMENDATIONS

Both pilots who participated in the flight test have experience with various rotorcraft and disaster response missions. In preparation for the flight test, the pilots participated in the UTM operation volume design and included the operation volumes in their pre-brief. During the flight, the co-pilot was looking at the operation volumes shown in the mission flight booklet (as presented in Figure 11 above) and provided oral advisories to the main pilot to aid in flight conformance with the operation volumes. Therefore, even though the pilot had awareness of each volume, he did not rely on an advisory display tool to help his stay within the volume.

Pilots commented that following the time component of the volume was relatively straight forward when considering the available temporal buffer applied to each operation volume segment. From their regular operations, pilots are used to making speed adjustments to meet time constraints and this experience contributed to the successful flight plan maintaining the expected arrival time.

With respect to the instances of conformance violations to the operation volume, the feedback from the pilots suggested that a visualization tool, such as a head-mounted display [13], could augment the operation volume with a visual image to increase positional awareness and reduce the likelihood of conformance violations. Salient alerts could also be provided through the display or with auditory cues prior to predicted non-conformance events. However, predicting non-conformance events is not straightforward for disaster response operations given that mission characteristics and expected pilot behavior may vary throughout the flight. Future work should consider preemptive means for alerting a pilot and providing situational awareness to allow better prediction of non-conformance.

Pilots also suggested that volumes need to be modifiable in flight but without significantly increasing the pilots' workload. An additional important functionality for efficient VFR operations and airspace management in disaster relief situations is "volume release," i.e., once the helicopter has completed the mission in the assigned volume, the airspace should be released and made available to other users. Ideally, this volume release should happen automatically once the vehicle leaves the volume or begins a mission in another volume. Final confirmation on the release should be issued by the pilot, using a mission support system such as D-NET's D-PAS. The timing of "volume release", how the pilots are informed of volume release, and concept details will be part of our future research.

Operation volume modifications were reported to be a necessary capability to provide the needed flexibility when the mission changes in flight and should be executed promptly and upon pilot's discretion. Some mission changes might require temporal and/or spatial operation plan modification, while other mission changes might be supported within the existing operation plan.

Landmarks play an important role in VFR flights. The flight test proved that large rivers, railroads, and highways provided clear guidance when the disaster did not affect their visibility. On the other hand, canals were more difficult to track. Bridges are clear and visible, but identification of specific bridges remain a challenge. The same is true for factories and school yards, often used as evacuation grounds- some schools have their name written clearly on the roof of the building (helicopter sign), but others do not. Some types of disasters such as fire and flooding might obstruct the distinction of visual landmarks where further research is needed. The pilots recommend that geographic landmark situation awareness can be better supported by a mission support system.

The operation volume concept for disaster response VFR flights needs further research, but both pilots agreed that using landmarks in the volume design reflected helpful VFR characteristics.

VII. CONCLUDING REMARKS

The flight tests conducted in December 2019 had the goal of examining the concept of landmark-based design of operation volumes when applied to manned flight operations under VFR within a D-NET and UTM-integrated environment. Test results and pilot feedback suggest that the approach taken to operation planning may have helped the pilots maintain conformance with their operation volumes. This conformance is important for the integration of manned air assets and UAS within a UTM-supported disaster response environment for predictability and planning. However, there were challenges identified during the flight test that warrant further refinement moving forward. Despite careful planning, three volume violations occurred. Pilot feedback suggested that overlapping current and previously flown volume segments while still active was confusing at times and contributed to the violations. The ability to release volume segments when exited was proposed as one step toward reducing confusion and increasing airspace efficiency. The use of wearable devices or heads-up displays for visual augmentation and more salient alerting to the pilot were also proposed as mitigations. Greater operation state flexibility in line with the dynamic nature of disaster response was also proposed along with the need for a more automated capability to update operation volumes prior to exiting volumes unintentionally or as a result of new mission tasking.

The results and feedback pave the way forward for continued development and refinement of the approach to operation volume design for manned operations under VFR, which will improve the overall effectiveness and safety of integrated manned and unmanned operations in disaster response situations supported by D-NET and UTM. The results also highlighted the need for better understanding and further research into the trade space between pilot flexibility and more structured airspace to support sUAS operations in the same operational area.

ACKNOWLEDGMENT

The authors thank JAXA’s Aeronautical Technology Directorate Flight Research Unit team for their dedicated support in conducting the flight test and obtaining data. The authors would also like to thank the NASA researchers and engineers that supported the flight test.

REFERENCES

[1] L. Ozdamar, "Planning helicopter logistics in disaster relief," *OR Spectrum* , vol. 33, no. 3, p. pp 655–672, 2011.

[2] Terra Drone, "Terra Drone Disaster Management," [Online]. Available: https://www.terra-drone.net/angola/domains/disaster-management/. [Accessed 4 3 2021].

[3] A. Andreeva-Mori, D. Kubo, K. Kobayashi, Y. Okuno, M. Johnson, J. R. Homola and P. H. Kopardekar, "Supporting Disaster Relief Operations through UTM: Operational Concept and Flight Tests of Unmanned and Manned Vehicles at a Disaster Drill," in *AIAA Scitech 2020 Forum*, 2020.

[4] G. Woo, D. Truong, and W. Choi, "Visual Detection of Small Unmanned Aircraft System: Modeling the Limits of Human Pilots.," *Journal of Intelligent & Robotic Systems,* pp. 1-15, 2020.

[5] FAA, "UTM Concept of Operations ver.2," 2 3 2020. [Online]. Available: https://www.faa.gov/uas/research_development/traffic_management/media/UTM_ConOps_v2.pdf. [Accessed 4 3 2021].

[6] Y. Okuno, K. Kobayashi, and H. Ishii., "Development of a helicopter operations management system for disaster relief missions.," *Journal of the American Helicopter Society* , pp. 1-9, 2016.

[7] J. Gomi, "Supporting Disaster Management with Space Applications," [Online]. Available: http://global.jaxa.jp/article/special/antidisaster/gomi_e.html. [Accessed 14 6 2016].

[8] A. Andreeva-Mori, K. Kobayashi and M. Shindo, "Evaluation of Satellite Imagery Integration in Optimal Aircraft Operation Planning for Disaster Relief," in *ICAS*, St.Petersburg, Russia, 2014.

[9] J. Homola, M. Johnson, P. Kopardekar, A. Andreeva-Mori, D. Kubo, K. Kobayashi and Y. Okuno, "UTM and D-NET: NASA and JAXA’s collaborative research on integrating small uas with disaster response efforts," in *2018 Aviation Technology, Integration, and Operations Conference*, 2018.

[10] Ministry of Land, Infrastructure, Transport and Tourism , "AIS Japan," [Online]. Available: https://aisjapan.mlit.go.jp/Login.do. [Accessed 15 2 2020].

[11] Ministry of Justice, Japan, "Japanese Law Translation Civil Aeronautics Act," [Online]. Available: http://www.japaneselawtranslation.go.jp/law/detail/?id=37&vm=02&re=02. [Accessed 18 2 2020].

[12] JAXA, "JAXA's Research Helicopter," [Online]. Available: http://www.aero.jaxa.jp/publication/pamphlets/pdf/heli.pdf. [Accessed 21 02 2020].

[13] K. Funabiki, H. Tsuda, A. Shimizu and Y. Sugihara, "Objective Flight Evaluation of Visual Cue for DVE Helicopter Operation," *AIAA Scitech 2020 Forum,* p. 0055, 2020.

AUTHOR BIOGRAPHIES

Dr. Adriana Andreeva-Mori holds B.Eng. (2007), M.Eng. (2009) and Ph.D. (2012) degrees in Aeronautics and Astronautics from the University of Tokyo. She has been with Japan Aerospace Exploration Agency since 2013, working on air traffic management, optimization, and new ATM operational initiatives.

Kohji Ohga is a licensed helicopter (BK 117 and Bel212) pilot. After serving in Japan Maritime Self-Defense Forces and Sendai-shi Fire Fighting Fleet, he joined Japan Aerospace Exploration Agency in 2014 as a test pilot.

Dr. Keiji Kobayashi has been involved in disaster relief aircraft operations research at Japan Aerospace Exploration Agency since 2009. He holds a Ph.D. from the Department of Environmental Engineering at Kyoto University.

Dr. Yoshinori Okuno holds B.Eng. (1985), M.Eng. (1987) and Ph.D. (1990) degrees in Aeronautics and Astronautics from the University of Tokyo. He has been with Japan Aerospace Exploration Agency since 1990, leading research on flight dynamics and aircraft operations.

Jeffrey Homola is a research psychologist in the Human Systems Integration Division at the NASA Ames Research Center. After serving in the US Navy, he went on to earn a B.S. in Cognitive Science from UCLA and an M.S. in Human Factors/Ergonomics from San Jose State University.

Dr. Marcus Johnson is a research aerospace engineer in the Aviation Systems Division at the NASA Ames Research Center. He is a graduate from University of Florida with a Ph.D. in Aerospace Engineering.

Dr. Parimal Kopardekar is the director of NASA Aeronautics Research Institute. He is the originator of the UTM concept and serves as the principal investigator for UTM research.