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Supporting Disaster Relief Operations through UTM: Operational Concept and Flight Tests of Unmanned and Manned Vehicles at a Disaster Drill

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Japan Aerospace Exploration Agency (JAXA) has been developing a system to manage resource allocation during disaster response operations and to optimize the application of available assets (D-NET). NASA has been engaged in research to enable the large-scale commercial application of UAS in low altitude airspace as part of the UAS Traffic Management (UTM) project. Since 2016, JAXA and NASA have partnered to investigate the safe and efficient integration of UAS in disaster relief operations. In October 2018, a flight test, which occurred as part of a large-scale disaster drill in Ehime Prefecture, Japan, successfully demonstrated that D-NET and UTM can contribute to the safe and efficient use of airspace by both manned and unmanned aircraft. This paper presents the technical challenges in UAS integration in disaster relief and D-NET/UTM integration and technical solutions developed to address these challenges. The scenarios used to test the integration of both systems in a real-world context, together with flight tests results and analysis are also shown. The flight tests successfully demonstrated the application of UASs to disaster response and showed they can safely cooperate with manned aircraft to improve response efficiency.

I. Introduction

Damaged ground infrastructure and vast disaster areas make the use of aircraft, both manned and unmanned, crucial for efficient disaster response. Aircraft and vehicle allocation, mission planning, and execution are usually managed by dispatchers at operation command centers set at local government or national levels. In cases of a large-scale disaster, however, human dispatchers and controllers need decision-support tools to manage limited resources safely and efficiently. Japan Aerospace Exploration Agency (JAXA) has been developing a system to manage resource allocation and provide real-time connection between aircraft and command centers during immediate post-disaster relief, and to optimize the application of available assets (D-NET) [1]. NASA has been engaged in research to enable the large-scale commercial application of UAS in low altitude airspace as part of the UAS Traffic Management (UTM) project [2]. Since 2016, JAXA and NASA have partnered to investigate integration of UAS in disaster relief operations. In October 2018, a flight test, which occurred as part of a large-scale disaster drill in Ehime Prefecture, Japan, successfully demonstrated that D-NET and UTM can contribute to the safe and efficient use of airspace by both manned and unmanned aircraft. Connecting the two remote systems (D-NET and UTM) in real time validated the mobility of the concept, which was an unprecedented endeavor to date. The benefit and applicability of UTM to the incorporation of UAV in disaster response efforts was also shown through data exchanges with D-NET and operators. Our previous work discussed the concept of integration of D-NET and UTM systems [3]. This paper will present:

1. Technical challenges in UAS integration for disaster relief, including review of current technologies and research

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2. D-NET/UTM integration and technical solutions developed
3. The scenarios developed to test the integration of D-NET and UTM in a live environment
4. Flight test: execution and results

II. Technical Challenges

A. Current Technologies Available and State-of-the-Art

Over the years, the use of UAS in support of disaster response efforts has become progressively more established. For example, dating back to 2005, Hurricane Katrina in the southern United States resulted in severe flooding [4]. Others like Hurricanes Florence and Harvey years later saw the increased use of UAS and a progression of technologies to aid in response efforts as well as greater levels of coordination across response agencies. However, while the use of UAS has increased and the technologies advanced, there has not been an established system in place to manage and coordinate multiple UAS operations between multiple operators that provided a common situational awareness of UAS assets and their status. This situational awareness is critical for operators as well as response managers in developing and maintaining an accurate assessment of the current deployment of assets and status of operations, which would aid in a more integrated and informed decision making process. In 2015, NASA formally embarked on the development and maturation of its UAS Traffic Management (UTM) concept as well as the technical development of the associated data and information architecture. The objectives of UTM are to enable a safe, scalable approach to the commercial application of small UAS in low altitude airspace that provides flexibility where possible and structure where necessary. The integration of Public Safety entities and their operations into the UTM ecosystem has been an early focus area and expectation. The application of UTM to disaster response efforts, therefore, is a natural extension of the concept that would provide the necessary coordination and situational awareness to facilitate a more optimal response. However, the traditional focus with regard to air assets and disaster response has been on manned aircraft operations. As a result, there are certain challenges in the further integration of UAS with manned aircraft into the overall response picture that require research. The tests performed by NASA and JAXA through the integration of UTM and D-NET systems is one step toward addressing those challenges and provides a path ahead.

B. Pre-flight (flight-planning) Phase Challenges

The technical challenges associated with UAS integration in disaster relief can be divided into pre-flight and in-flight phases.

In the pre-flight phase, the following challenges should be addressed.

1) Are missions optimally assigned considering available resources and disaster area?
In the immediate aftermath of a large-scale disaster, demand (search and rescue missions) exceeds available resources (manned and unmanned aircraft, ground vehicles, etc.), which makes vehicle assignment and route planning an optimization problem. Vehicle routing has been subject to multiple studies [5], [6], but the scale of the problem and fleet heterogeneity pose a problem in real-world applications.
This particular challenge will be addressed in a follow-on publication.

2) Are the generated flight plans conflict-free?
Disaster relief missions are often performed by vehicles belonging to different organizations, which do not necessarily coordinate their planning. D-NET centralized mission assignment and flight planning can solve this issue, but the option for UASs operated by different operators still needs to be considered. Here, using D-NET/UTM translator software (DLinkUTM), real time conflict-free operations were planned and verified. UTM provided the necessary safety separation margins.

3) When flight plans are not conflict-free, can the conflict be resolved by re-planning?
Strategic deconfliction of the 4 dimensional flight plans can be done by either changing the flight plan geography or shifting the flight plan in time. UTM provided information to D-NET for re-planning as part of strategic deconfliction.

C. In-flight Phase Challenges

The in-flight phase poses the following challenges:

1) Is the UAS flying according to its flight plan?

UAS real time telemetry data are transmitted from D-NET to UTM via DLinkUTM. If position report frequency does not meet the minimum requirements set by UTM, the UAS will be treated as non-conforming vehicle. UTM checks conformance between the flight plan and actual flight, and issues alerts as needed.

2) Can the UAS transmit survey information (e.g., victim's location)?

A main advantage of UAS is the wide variety of payload and equipment they can carry onboard. In reconnaissance missions, information transmitted live from an onboard camera is used to evaluate the damages and identify victims' locations in real time. In this test, there was no camera onboard the UAS, so the second challenge was not tested. However, the state of the victim and disaster area information can be shared through D-NET [7], [8].

3) Is the UAS aware of other traffic (manned and unmanned) in the airspace and, if necessary, can the UAS modify its flight plan to avoid conflict?
Nominal UAS operations will, in general, follow a flight plan developed and agreed with operators and relevant players prior to the flight. In the case of disaster relief, however, flights of both manned and unmanned vehicles will often differ from the original flight plans due to the nature of missions (search and rescue, for example). Therefore flight plan modification capability is necessary. In this test, manned aircraft (JAXA's experimental helicopter) flight plan and position data were submitted to UTM and the vehicle was treated as a priority user. Alerts were issued to UAS in the airspace resulting in plan modification to allow the vehicle to safely return to base.

III. D-NET/UTM Integration

The integrated system between JAXA's D-NET and NASA's UTM is focused on the safe and efficient use of UASs in immediate post-disaster relief operations. The integrated operations are described in two stages, corresponding to the technical challenge stages (pre-flight and in-flight) discussed in Section II. Mission assignments and planning are done in D-NET, thus all trajectories are generated there. Each UAS and helicopter flight plan is essentially a trajectory, made of multiple line segments, each defined by the 4D coordinates of its edges. Based on the received UAS trajectories, UTM checks that safety constraints are met and sends operational volumes back to D-NET. Helicopter operations, however, are visual flight rules (VFR) operations, which often results in large deviations from the original flight plan used only as a reference. Originally, UTM was not designed to aid manned aircraft VFR operations, so the volumes which would be generated based on the line segmented flight plans will not be sufficiently large to account for actual disaster relief helicopter VFR operations. The current D-NET/UTM integration adapts existing capabilities of both systems. Therefore, helicopter VFR flights plans are submitted to UTM not as line segments, but as relatively large operational volumes. Current disaster relief practices prioritize manned over unmanned aircraft operations. In other words, even if there is an accepted UAS operation in a certain airspace, helicopter's mission will be given priority. To model accurately such practices, the helicopter is treated as a priority user and its flight plan is always accepted by UTM. UTM can either accept or reject a UAS plan, though. The conceptual interaction between D-NET and UTM in the pre-flight stage is shown in the left panel of Fig. 1.

At the in-flight stage (Fig. 1 right panel), D-NET provides UAS and helicopter tracking data to UTM. UTM checks the conformance of and can then issue alerts when necessary. Performing conflict detection at both planning and in-flight stages contributes to safe mission execution. UAS information (operational volumes and current position) is sent to the helicopter as well via a newly-developed function of the already existing D-NET onboard mission support system [8]. Further details on the initial architecture and overall concept of operations exploration can be found in [3].

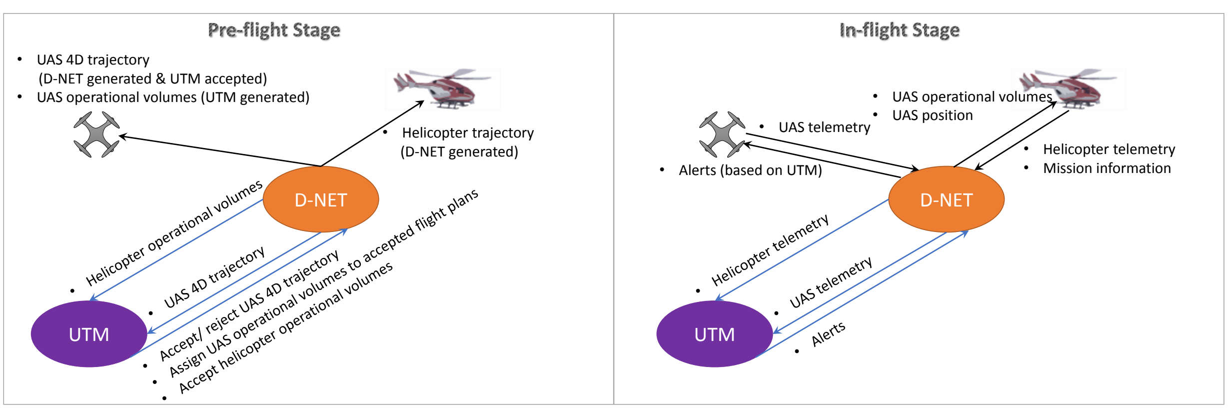

Fig. 1 D-NET/UTM conceptual interaction

In advancing the concept and addressing the above challenges, D-NET and UTM were required to interface and communicate in real-time to each other. Although D-NET and UTM can serve as portable systems they were not initially designed to exchange information. To address this issue and enable integrated support for disaster relief in real time, translator software referred to as DLinkUTM was designed and developed. Fig. 2 presents the architecture and information flow of the integrated system. All information exchanges between D-NET and UTM were established through DLinkUTM, which maintains concurrent connections to D-NET servers and UTM. Fig. 3 presents a snapshot of the DLinkUTM interface in which the green fields marked "DCSV" and "UTM" represented active DLinkUTM connections to D-NET and UTM respectively. The interface also provides information on the vehicle's ID (e.g., UAV001, UAV002, etc. in Fig. 3), the UTM state of the operation (ACCEPTED for a flight plan been accepted by UTM, REJECTED, CANCELLED, etc.), the Globally Unique Flight Identifier (GUFI), and flight plan number for each vehicle.

D-NET/UTM integration required that UAS operational volumes be visible onboard the helicopter in real time. This was achieved by adding such functionality to the existing onboard D-NET mission support technology. D-NET's mission support tool is a fully portable system, consisting of a satellite transmission component, a digital antenna and a touch-screen display which enables manual input on behalf of the operator onboard the helicopter.

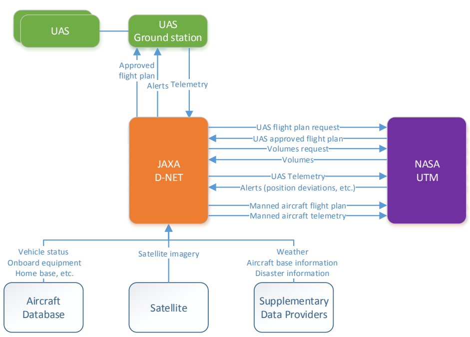

Fig. 2 D-NET/UTM interface architecture

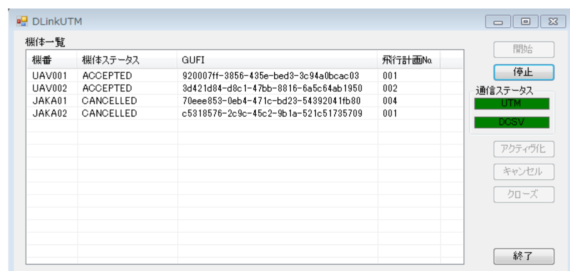

Fig. 3 DLinkUTM translator software snapshot

Fig. 4 D-NET fully-portable onboard mission support system

IV. Test Scenario

To test the integration of D-NET and UTM in a realistic and applied context, the following test scenario was developed. Following a major disaster event, UASs supported by UTM were assigned to search the disaster area for evacuees. While performing the searches a person is discovered awaiting rescue. This information is shared through D-NET and a manned helicopter is assigned to perform the rescue. The intended operating area of the helicopter is communicated through UTM as a priority operation. In its response, the rescue helicopter enters the airspace originally assigned to UASs, which results in notifications via UTM to the UAS operators and subsequent procedures to clear the airspace. The helicopter is free to quickly extract and transport the person to a safe location. Unlike in nominal operations, in disaster response it is very likely to have a manned aircraft (most often a medevac or rescue helicopter) enter airspace originally assigned to an UAV. For all vehicles to operate safely, mission prioritization, planning and execution become crucial. The scenario developed for this flight test provided the opportunity to test the capabilities of both systems (D-NET and UTM) with respect to these challenges.

V. Flight Test

Based on the above general scenario, a detailed 17-step flight test plan shown in Fig. 5 was developed and conducted successfully. Strong winds prevented the live UAV from flying on the day of the disaster drill, but the UAV was substituted by a simulated vehicle. The manned aircraft (JAXA's experimental helicopter) was able to fly and its flight plans and positioning data were successfully transmitted to UTM. On the day of the disaster drill, two series of flight tests were conducted- one in the morning and one in the afternoon. Both followed the same scenario and flight plan as shown in .

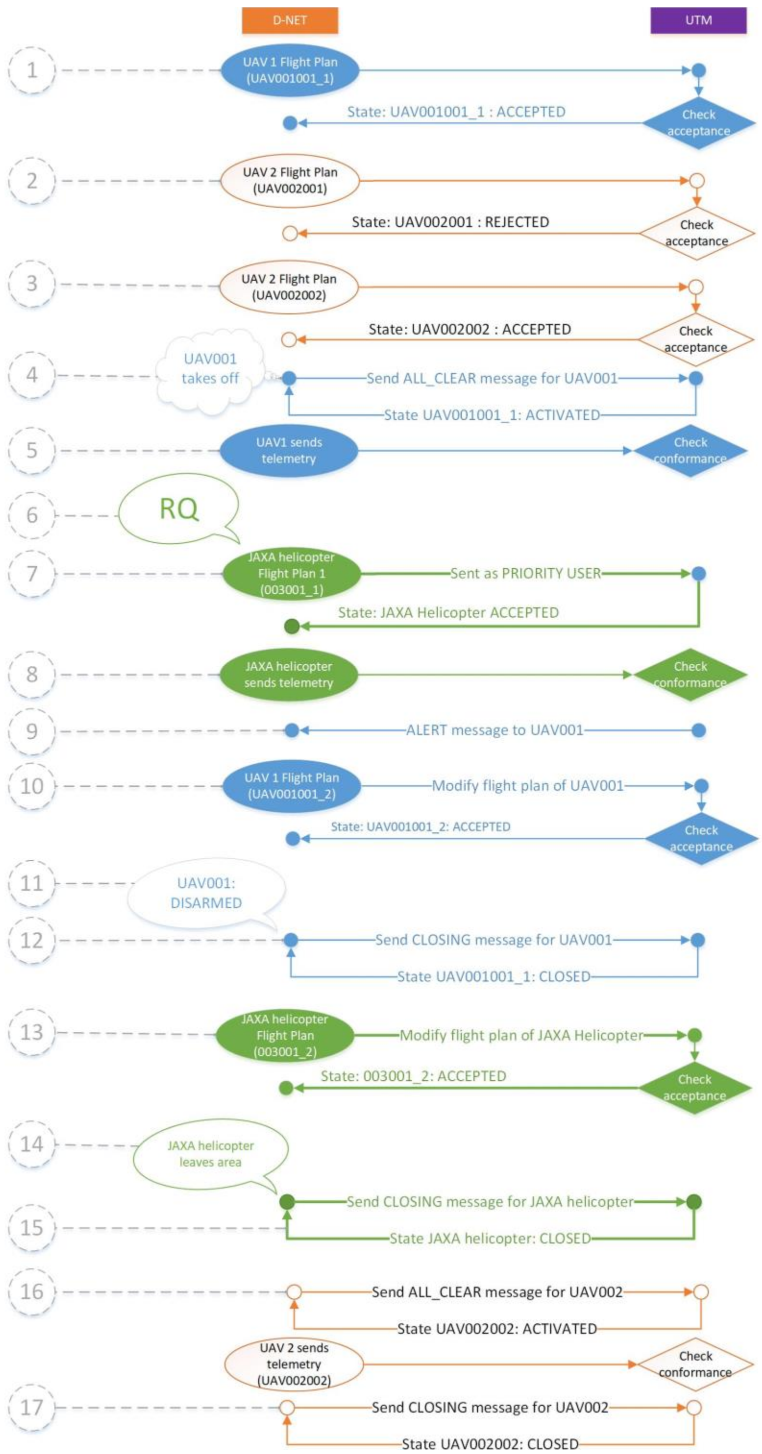

Fig. 5 Flight test plan

A. Test Setup

In support of the flight test, multiple teams of personnel across multiple locations were involved serving in different roles. In Japan, two teams were on station. One team was located at the disaster drill's dedicated Operations Center in Matsuyama City, Ehime Prefecture. This team consisted of JAXA and NASA researchers and technical staff that monitored the simulated disaster situation and interfaced with the D-NET and UTM systems. Information exchanges with the respective systems were managed from the Operations Center and operational situation awareness was maintained through monitoring of data via various interfaces (Fig. 6). Another team of JAXA and NASA researchers was located out on the peninsula accompanied by a flight crew and their vehicle. This team's role was to conduct live flight operations of a UAS in support of a coordinated disaster response effort (Fig. 7). A third team was located at NASA Ames Research Center in California within the Airspace Operations Laboratory (Fig. 8). 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. Systems health were also monitored from the laboratory during the test to ensure continuous connectivity and proper functioning. There was also the helicopter crew that performed the live manned flight and enabled the interaction with UAS supported through UTM.

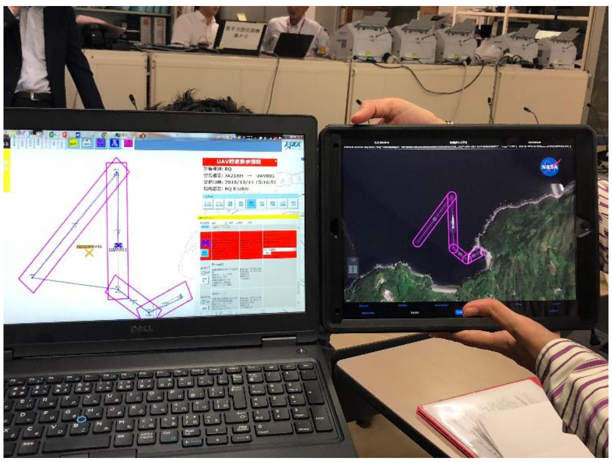

Fig. 6 D-NET and UTM interfaces used by researchers in the Operations Center

Fig. 7 Crewmember of the flight team at the UAS site

Fig. 8 Airspace Operations Laboratory at NASA Ames Research Center

B. Pre-flight (flight-planning) Phase

At the beginning of the test, D-NET was connected to NASA's UAS Service Supplier (USS) through DLinkUTM. D-NET provided flight plans compatible with UTM's flight plan format. The flight plan consisted of several 4D line segments, each defined by two 3D points and begin/end times (Table 1). The flight plan for UAV1 (UAV001001_1) was sent to UTM, which confirmed there were no conflicting flights in the same airspace and sent an ACCEPTED message and associated operational volumes (safety separation margins) for each flight segment. GUFI was assigned to UAV001001_1 at this point by UTM. Next, flight plan UAV002001 was sent to UTM, but since it overlapped partially with the already accepted UAV001001_1, it was rejected. A key element of the UTM concept is strategic deconfliction where, for example, two operations would not be able to share the same airspace without further negotiation. In this case, UAV002001's operation was rejected due to the geographic and temporal overlap of volumes. The flight plans were then manually de-conflicted by time shifting the flight plan of UAV2. Note that undergoing development includes automatic spatial and temporal de-confliction. The newly-generated flight plan UAV002002 was then submitted to UTM (Step 3) and accepted by the system. The first three steps addressed the pre-flight challenges discussed in Section II. The flight plan submission times and responses are shown in Table 2. At the end of step 3, the dispatchers at the operation centers knew what time the search over the target areas would be completed, thus allowing them to plan accordingly for other missions. Furthermore, the time between flight time submission and UTM's response showed that both systems can communicate in real time with minimum delay.

Table 1 UAV001001_1 flight plan details

							Dist [m]	Speed [m/s]	Flight time [s]	Flight time	Nominal_Begin	Nominal_End		FP_BEGIN	FP_END
WP1	132.341428	33.504698		Segment1	WP1	WP2	99.7	3	33	0:00:33	9:15:00	9:15:33	Segment1	9:10:00	9:20:33
WP2	132.340471	33.504267		Segment2	WP2	WP3	111.7	3	37	0:00:37	9:15:33	9:16:10	Segment2	9:10:33	9:21:10
WP3	132.339553	33.504891		Segment3	WP3	WP4	233.6	3	78	0:01:18	9:16:10	9:17:28	Segment3	9:11:10	9:22:28
WP4	132.337071	33.505251		Segment4	WP4	WP5	371.4	3	124	0:02:04	9:17:28	9:19:32	Segment4	9:12:28	9:24:32
WP5	132.339507	33.507903		Segment5	WP5	WP3	333.5	3	111	0:01:51	9:19:32	9:21:23	Segment5	9:14:32	9:26:23
				Segment6	WP3	WP2	111.7	3	37	0:00:37	9:21:23	9:22:01	Segment6	9:16:23	9:27:01
				Segment7	WP2	WP1	99.7	3	33	0:00:33	9:22:01	9:22:34	Segment7	9:17:01	9:27:34

Table 2 Flight plan submission times

Step	Event	Submitted by	Submitted to	Time as recorded by DLinkUTM
1	UAV001001_1 submission	D-NET	UTM	08:44:06
1	UAV001001_1 acceptance	UTM	D-NET	08:44:10
2	UAV002001 submission	D-NET	UTM	08:44:22
2	UAV002002 rejection	UTM	D-NET	08:44:24
3	UAV002002 submission	D-NET	UTM	08:44:46
3	UAV002002 acceptance	UTM	D-NET	08:44:48

C. In-flight Phase

In accordance to its flight plan accepted by UTM, UAV001 could take off no earlier than 9:10:00 and complete the first leg of the mission between WP1 and WP2 no later than 9:20:33. Once the take-off preparations (this time, simulator run preparations) were completed, an "ALL CLEAR" message was sent from D-NET to UTM to activate the mission. The simulator DLinkUTM were operated at two different locations to simulate real disaster response environment, and connection between the UAV operator and DLinkUTM was established over a mobile phone. To assure that UAV001 did not go in non-conforming state, i.e. that UTM was aware of the position of the vehicle and it complied with the corresponding volume, UAV001 telemetry transmission to D-NET started prior to take-off. Once the UAV001 State became ACTIVE, positioning data was sent via DLinkUTM at one-second intervals. Each position update was checked against the operation volumes of the flight as part of conformance monitoring. Screenshots of D-NET and UTM user interfaces taken at 09:11 JST are shown in Fig. 9 and Fig. 10. At 09:11, Segments 1 and Segments 2 are shown as ACTIVE (the lines defining the volumes are bold), while the remaining segments are not active yet. Since UAV001 has not taken off yet, its flight plan is ACCEPTED (shown in the light green rectangular field in the bottom right corner). A comparison with NASA's visualization tool screenshot shows that both systems could successfully communicate with one another despite their different geographic locations. Telemetry transmission of UAV001 after its takeoff at 09:14:03 completed steps 4 and 5.

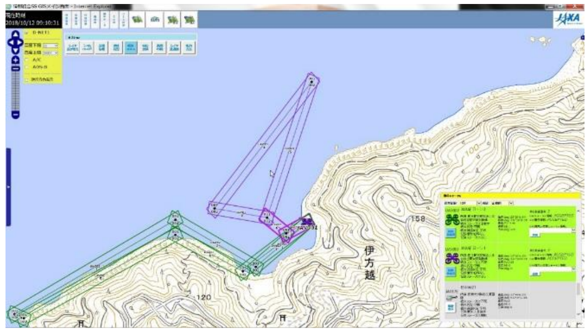

Fig. 9 D-NET visualization tool screenshot at the Operation Center in Ehime, Japan

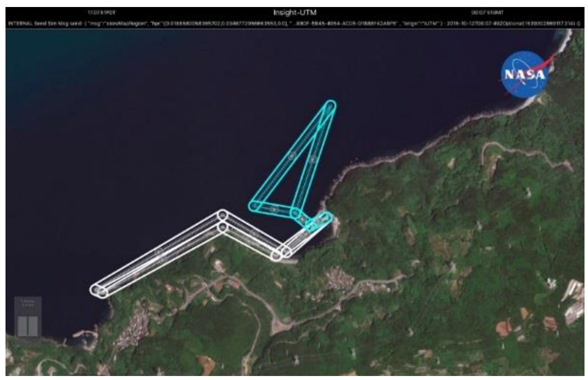

Fig. 10 UTM visualization tool screenshot from NASA Ames Research Center, USA

According to our scenario, UAV001 discovered a person needing rescue and relayed that to D-NET, which, in turn relayed the victim's location to the manned aircraft, JAXA's experimental helicopter JA21RH. The operational volume information of the UAVs was relayed to D-NET's onboard mission support system and shown to the crew, as seen in Fig. 11. The helicopter crew was therefore informed of the UAV's flight plan (bold yellow line) and assigned operational area (yellow shaded area), as seen in Fig. 12. This contributed to the pilot's awareness and his preparedness to plan trajectory changes.

Fig. 11 Onboard D-NET portable system view. UAV area is shown in yellow, and the present helicopter position is shown by the red arrow.

Fig. 12 Sample zoom-in of the UAV flight zones as seen onboard D-NET portable system. The yellow areas represent the airspace assigned to UAVs.

Next, at step 6, using D-NET onboard mission support system, a request from the helicopter to UAV001 to clear the airspace was sent and received by D-NET at 09:15:56. Handling the manned aircraft as a planned mission within UTM required adaptation of existing capabilities, in particular submitting an operational volume to cover the helicopter flight. JA21RH was a visual flight rules (VFR) flight, but for the purposes of this flight test operational volumes analogous to the ones assigned to UAV001 were submitted to UTM. The volumes submitted only covered the portion of JA21RH's flight in the proximity of the UAV's area, as shown in Fig. 13 left panel (a later flight included operation volumes that covered the entirety of the helicopter's flight path to the rescue site (Fig. 13 right panel). JA21RH departed from Matsuyama Airport located approximately 50 km away from the UAV flight zone, and it was visible to UTM as a planned operation once it was in the volumes about 10 km away from the UAV flight zone. Meanwhile, during the in-flight phase, the operation was monitored for conformance with real-time status available for situation awareness. JA21RH's operational volumes overlapped with UAV001001_1 volumes already accepted by UTM. In general, UTM assigns airspace based on the first come, first served rule, which would not allow the helicopter to rescue the victim. Therefore, priority user's functionality of UTM was adapted. Flight plan 003001_1 was sent from D-NET to UTM as a priority user and was accepted at (step 7). The telemetry of the helicopter which was transmitted through D-NET's onboard mission support to D-NET on the ground was then relayed to UTM. Position reports from the helicopter to D-NET are available every 20 sec, since the transmission is established through satellite connection and due to cost considerations more frequent reports were not feasible. UTM requires more frequent position reports, so DLinkUTM kept sending the most recent position every second until a position update from the aircraft was available. Upon receiving the flight plan of the priority user JA21RH, UTM sent an alert to D-NET for UAV001 to clear the airspace. D-NET then created a new flight plan for the UAV001 to return to base. The modified flight plan UAV001001_2 included only the current segment and the future segments necessary for the return flight. The flight plan modification needed to be done while UAV001 was flying between WP3 and WP4' (see Fig. 14). UAV001001_2 was accepted by UTM and the vehicle could then return safely to base (Fig. 14 and Fig. 15). The UAV operators disarmed the vehicle (step 11) and this information was relayed over a mobile phone to the operation center. DLinkUTM sent a CLOSING message to UTM which closed the mission (step 12). Once the airspace was clear, JA21RH operational volumes were modified to include the airspace previously assigned to UAV001 so that the helicopter can complete its rescue mission of the victim located by the unmanned vehicle. The flight tests at the disaster drill did not include actual landing, but the helicopter flew over the UAV airspace instead. Once JA21RH left the UAV airspace (step 14) and its assigned volumes, the mission was closed (step 15). The original scenario included testing of the simulated UAV002 as well, but since UAV001 flights were substituted by simulations due to bad weather, the UAV002 simulations were not conducted, so steps 16 and 17 were omitted.

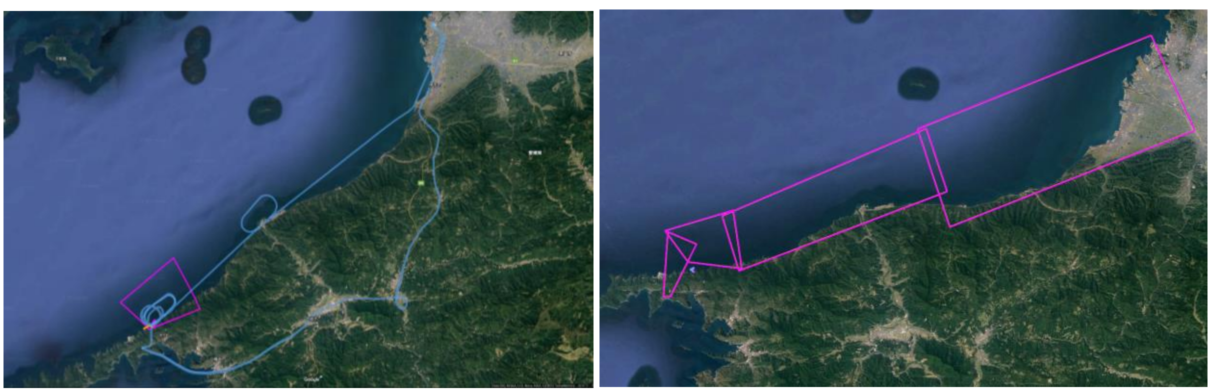

Fig. 13 (Left panel) The helicopter operation volumes (shown in magenta) submitted to UTM only covered the portion of the flight near the UAV area (shown in orange). The light blue track shows the entire helicopter trajectory from its takeoff from Matsuyama Airport to its landing at the same airport. (Right panel) The second helicopter flight included a set of operation volumes that encompassed the helicopter's flight path from takeoff location to the rescue site.

Table 3 UAV001001_2 flight plan details

							Dist [m]	Speed [m/s]	Flight time [s]	Flight time	Nominal_Begin	Nominal_End		FP_BEGIN	FP_END
WP1	132.3415	33.5046		Segment1	WP4	WP4'	190	3	63	0:01:03	9:17:28	9:18:32	Segment1	9:12:28	9:23:32
WP2	132.3405	33.50427		Segment2	WP4'	WP3	220	3	73	0:01:13	9:18:32	9:19:45	Segment2	9:13:32	9:24:45
WP3	132.3396	33.50489		Segment3	WP3	WP2	111.7	3	37	0:00:37	9:19:45	9:20:22	Segment3	9:14:45	9:25:22
WP4	132.3371	33.50525		Segment4	WP2	WP1	99.7	3	33	0:00:33	9:20:22	9:20:55	Segment4	9:15:22	9:25:55
WP4'	132.3383	33.50658													

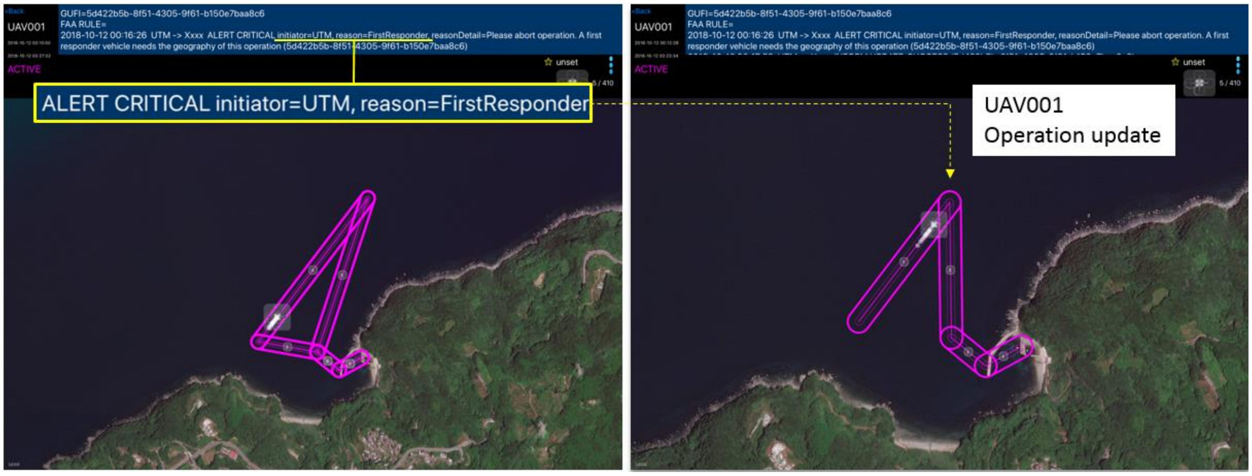

Fig. 14 UAV001 was sent an alert informing of priority user in the same airspace

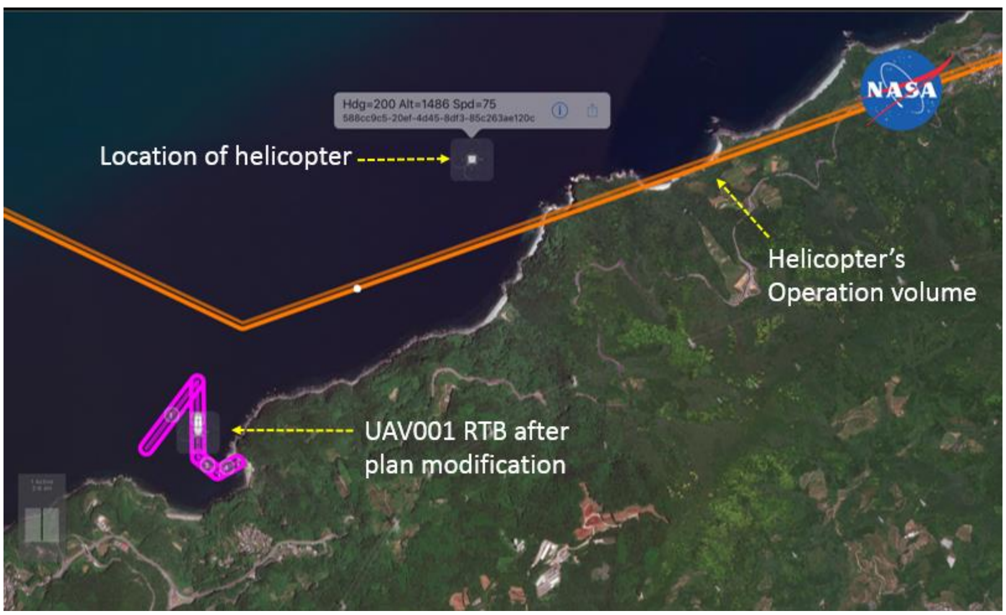

Fig. 15 Helicopter's operational volume, location and UAV001 modified flight plan

VI. Flight Test Results and Analysis

The detailed scenario that was developed allowed for multiple D-NET and UTM capabilities to be tested in a realistic disaster recovery environment.

D-NET and UTM were able to communicate to provide sufficient information exchange for disaster recovery support. Throughout preparation and testing, 117 operations were submitted to UTM (Table 4). 363 messages were exchanged between both systems through DLinkUTM. The number of positions submitted was 5364, as most operation exchanges were meant to test flight planning capabilities and thus did not include position reports. Therefore, there was a high number of cancelled operations, as seen in Fig. 16. Flight planning is crucial for efficient disaster relief and this collaborative test demonstrated that UTM and D-NET can be used for tactical planning as well. Throughout preparation and testing, 79 alerts were sent to D-NET (Table 5). These alerts contributed to safe mission execution and proved that both systems are complementary.

Table 4 Number of information exchanges throughout preparation and testing

Information exchanges	Counts
Operations	117
UTM Messages	363
Positions	5364

Table 5 Message types and counts observed across preparation and testing

Message Categories	Counts
INFORM	203
INTENT	81
ALERT	79

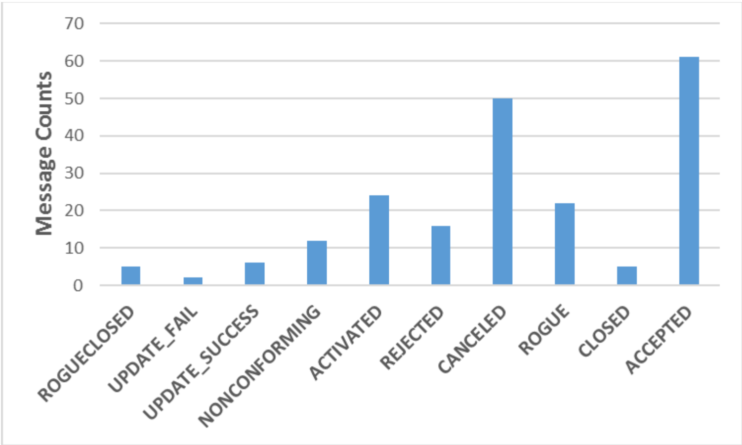

Fig. 16 Operation statistics (preparation and testing)

VII. Concluding remarks

The flight tests conducted at the 2018 Ehime Prefecture disaster drill successfully demonstrated the application of UAVs to disaster response and showed they can safely cooperate with manned aircraft to improve response efficiency. Connecting two remote systems (D-NET and UTM) in real time validated the mobility of the concept. The benefit and applicability of UTM to the incorporation of UAV in disaster response efforts was also shown through data exchanges with D-NET and operators. Additionally, the integration of UTM enabled informed planning for safe operations and facilitated situation awareness, which are critical elements in disaster response environments. It was the first time to have a manned aircraft as a planned operation in UTM, a demonstration of concept and technology which went very successfully. The disaster drill flight tests also exposed some of the challenges for D-NET and UTM in disaster response applications. Finally, gaining an understanding of the ways in which operators would use the information from both manned and unmanned aircraft in such situations provided very valuable feedback for future development.

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