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NEW ENTRANTS' AIRSPACE INTEGRATION IN JAPAN: JAXA'S ONGOING CONTRIBUTION

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Abstract

Initial UAS and eVTOL use cases in Japan are expected to focus on disaster response applications. The Japan Aerospace Exploration Agency (JAXA) has identified technical challenges, including surveillance, flight intent sharing and mission information sharing, for such UAS and eVTOL integration. To address these challenges, JAXA plans to leverage the existing technologies and expertise gained through JAXA's Disaster Relief Aircraft Information Sharing Network (D-NET) and investigate how long-term use cases can benefit as well.

Keywords: UAS, eVTOL, Operation, Airspace Integration.

1. Introduction

Recent technological advances have demonstrated the potential of unmanned aircraft systems (UAS) and electric vertical takeoff and landing vehicles (eVTOL) as future transportation means. These new entrants are expected to meet the demand for (very) short-haul flights and unlike most scheduled civil airliners are to fly in low-altitude airspace. The operational scope, therefore, is expected to result in high regional versatility. Worldwide, a lot of the demand is found in high-density metropolitan advanced air mobility, such as on-demand air taxis transporting people from the airport to the city center, for example [1][2]. In addition to the above use case, Japan's unique terrain predisposes to low-density operations in mountainous and remote-island areas, where ground access is either limited or time-consuming. The government of Japan, along with stakeholders in the public and private sectors, has researched and identified the use cases of projected UAS and eVTOL domestic applications [3]. Starting from package delivery services in isolated islands and passenger transportation services in limited areas, commercial passenger transportation service between aerodrome and surrounding coast area is envisioned for Osaka's Expo held in 2025 (Fig.1). Meanwhile, as one of the most disaster-prone countries worldwide, future air mobility's application to disaster response have been in the spotlight as well. Such public services would be the good start point of new technology application because participants are limited to experienced operators and introduction cost reduction pressure could be relaxed compared to commercial services. Early application in public services would help us identify technical challenges and potential solutions in forthcoming wide commercial applications. Therefore, the Japan Aerospace Exploration Agency (JAXA) expects that initial UAS and eVTOL applications would be first demonstrated in such off-nominal scenarios and therefore JAXA has been focusing on research and development of operation technologies to support UAS and eVTOL integration into disaster response applications.

This paper discusses applications and technological challenges of new entrants such as UAS and eVTOL in Japan, and raises research questions regarding the broader, long-term applications relevant to the entire international community.

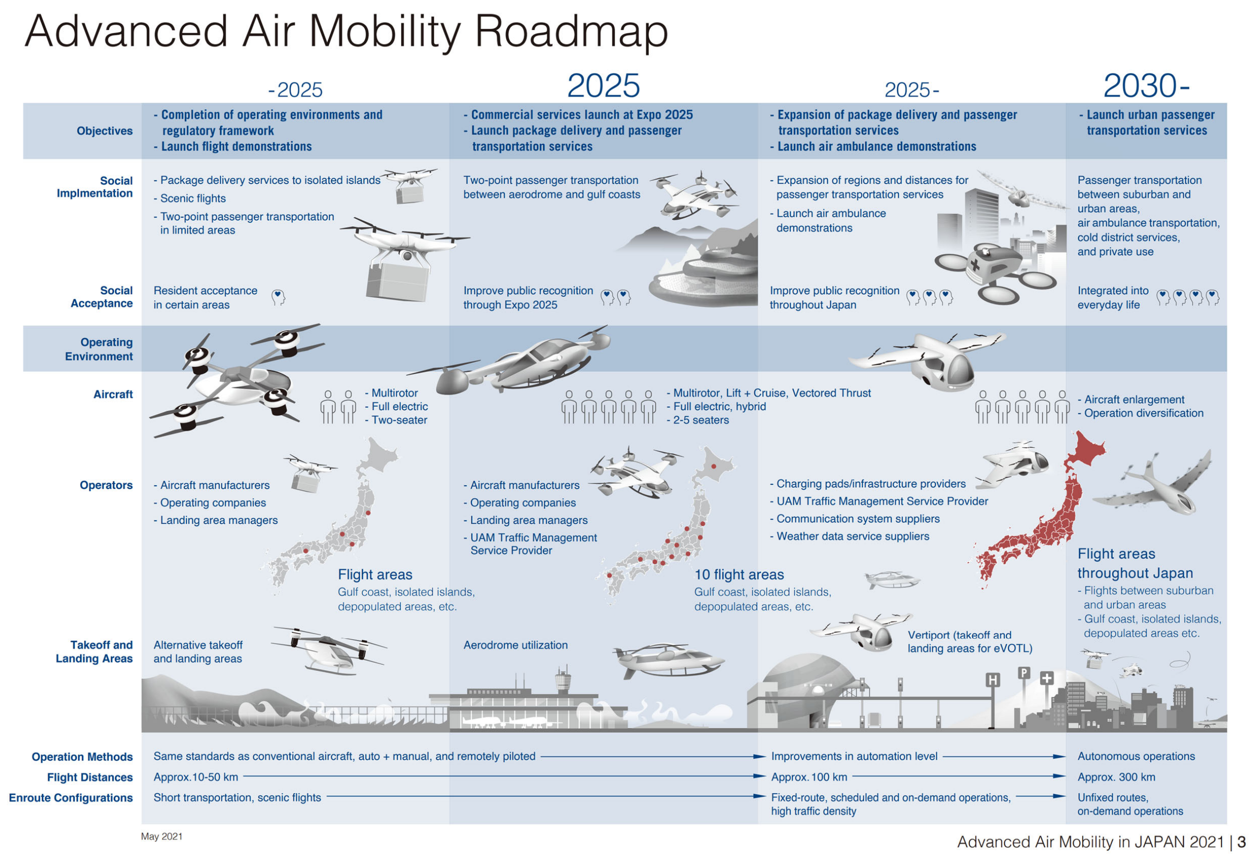

Fig. 1 Advanced Air Mobility Roadmap in Japan. (Quoted from ref. 3)

2. Leverage of Existing Expertise and Technology

2.1 Disaster response technology- the beginning

Compared to other countries, Japan has already an established platform for information sharing and low-altitude flight integration focused on aircraft disaster response activities. Lessons learned from previous disasters have identified technological challenges which need to be addressed for safe and efficient aircraft integration. Some main challenges are:

1) Surveillance technologies and telemetry reporting during flight at low altitudes,
2) Mission information sharing among aircraft and ground operation centers.

These technological challenges have been addressed by JAXA’s Disaster Relief Aircraft Information Sharing Network (D-NET) [4] (Fig .2). D-NET assures efficient and safe information gathering, planning and operation execution by connecting aircraft, operation centers and other relevant stakeholders. D-NET has the following functions:

- Surveillance: By bringing a portable D-NET onboard terminal equipped with GPS and Iridium satellite communication capabilities on board the aircraft, D-NET ground station can monitor aircraft position in real time. Alternatively, secondary surveillance radar information can also be used.
- Disaster/mission information sharing: Stakeholders including aircraft and operation centers can share Information necessary for carrying out the disaster-relief mission, such as fire locations or rescue-required person locations, by using D-NET on-board and ground terminals equipped with information display and input devices. Satellite images showing broader area information also can be shared by D-NET [5] (Fig. 3). In addition, since the ground station shares information on aircraft equipment, it is possible to dispatch aircraft with optimal equipment to the required location, such as dispatching a doctor helicopter with medical equipment to transport seriously injured persons.

All firefighting helicopters and doctor helicopters in Japan have introduced D-NET compatible systems, and are gradually being introduced to the National Police Agency and other disaster-relief agencies (Fig. 4).

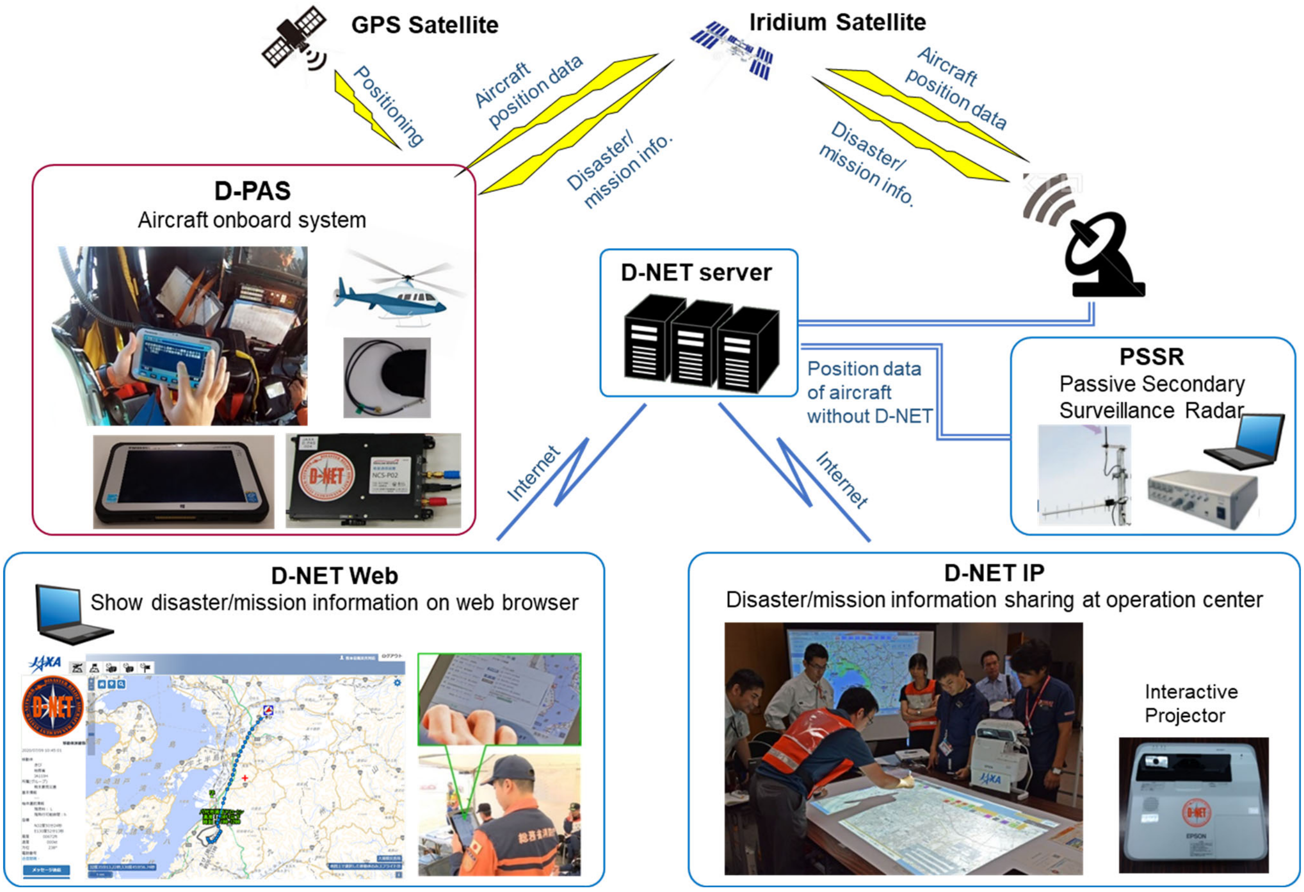

Fig. 2 D-NET system

Before D-NET introduction

Attach labels on paper map showing disaster information, such as flooded area and rescue-required person location, and share information with flying helicopters via radio.

After D-NET introduction

Show disaster information on digital map and share information with flying helicopters immediately via satellite datalink.

Fig.3 Comparison of disaster/mission information sharing at operation center before and after D-NET introduction.

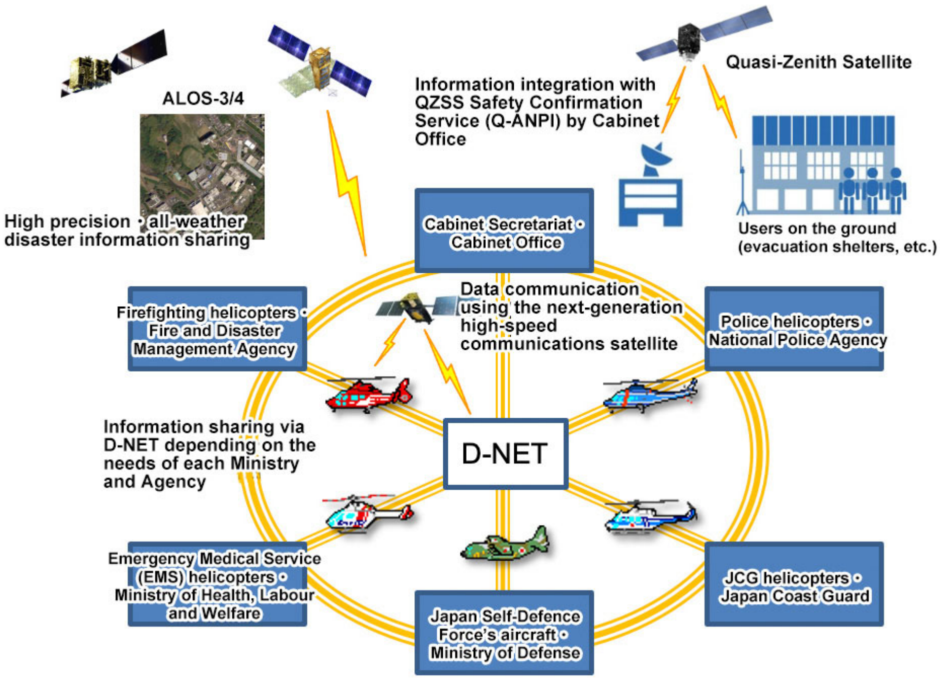

Fig.4 D-NET network connecting Japanese government agencies.

2.2 Application to the Tokyo 2020 Olympic/Paralympic games- expand to airspace management support

D-NET's technology was leveraged to support the Tokyo 2020 Olympic/Paralympic games as well. D-NET was utilized to apply flight restricted airspace around the game sites. In this application, we identified a new technological challenge:

3) Intent sharing and coordination capabilities at the strategic planning level.

Since the games were held in Tokyo metropolitan area, there were a lot of VFR traffics. Flight plan coordination in pre-flight phase between multiple operators was critical for successful airspace control. For this purpose, we added the following function to D-NET:

- Flight plan coordination: D-NET defines a common format of flight plan. Operators submit the flight plan to D-NET according to that format. The D-NET ground station visualize the submitted flight routes in chronological order and detecting the interference between routes. This feature allows to adjust the flight plan of many aircraft operated by multiple organizations in a short time.

As a result, D-NET enabled to coordinate flight plans of more than 500 aircraft in pre-flight phase, and to monitor aircraft locations in flight phase (Fig. 5). D-NET allowed efficient operations of aircraft permitted to fly within the restricted airspace for security and broadcast purposes, as well as early detection of suspicious aircraft flying without permission.

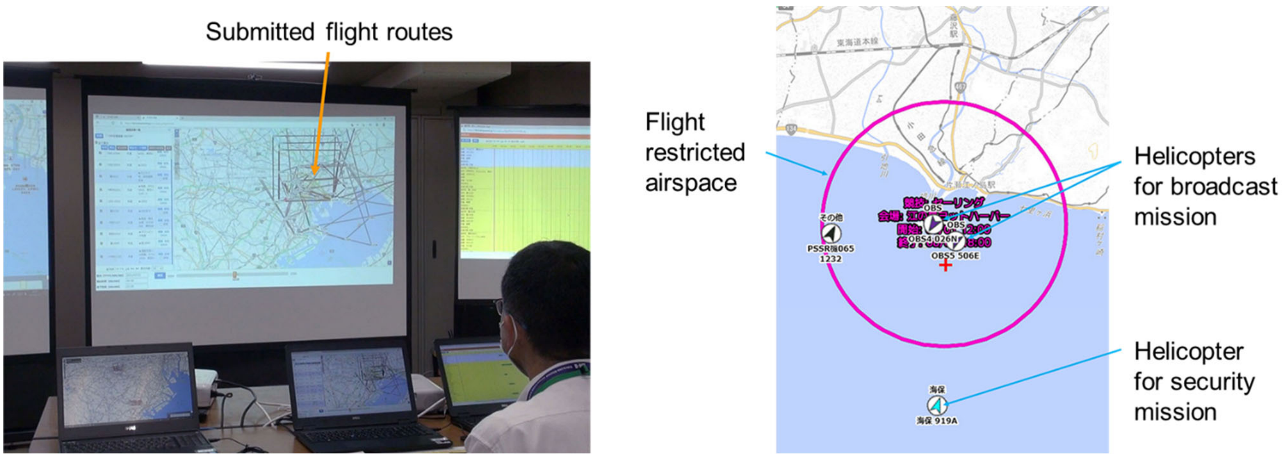

Fig. 5 Flight plan coordination in pre-flight phase (left) and aircraft monitoring in flight phase (right) using D-NET at Tokyo 2020 Olympic/Paralympic games.

3. Future steps: on the way to advanced air mobility

Given Japan is a disaster-prone country, the initial UAS and eVTOL applications are expected in disaster response operations first. In these off-nominal scenarios, existing manned aircraft would share low altitude airspace with UAS and eVTOL. For example, a manned aircraft (helicopter) conducting a rescue mission based on reconnaissance information from UAS might need to enter the very low-altitude airspace officially assigned to UAS. Such airspace sharing and dynamic modification capabilities would be also applicable to most UAS and eVTOL operation scenarios conducted in suburban areas with moderate operational density. Therefore, the following technical challenges faced by D-NET are also valid for integration of UAS and eVTOL operations into low altitude airspace:

1) Surveillance technologies and telemetry reporting during flight at low altitudes,
2) Mission information sharing among aircraft and ground operation centers,
3) Intent sharing and coordination capabilities at the strategic planning level.

D-NET's expertise, platform, lessons learnt, and data collected therefore can be utilized to realize the integration of UAS and eVTOL. Still, D-NET needs further research and improvement in many aspects for this purpose. Some major challenges to be addressed are as follows:

- Reliable surveillance by multiplex means: D-NET's surveillance information sharing using Iridium satellite communication can have a delay in the order of minutes due to its slow communication speed. In some cases, communication is lost due to technical reasons including satellite's arrangement. In order to realize higher-density operations, delay reduction and reliability improvement of communications are necessary. JAXA plans to introduce multiplex communication system combining high-speed satellite communication and mobile phone communication. In addition, as a monitoring means for aircraft without D-NET onboard devices, affordable aircraft location transmitter would be necessary, especially for low altitude operations where secondary radar is not available. Portable ADS-B is promising candidate and JAXA is evaluating its transmission coverage under actual flight environment for its introduction in Japan.
- Intent sharing among manned aircraft, UAS and eVTOL: JAXA has also conducted research and development on UTM that manages the operation of UAS, together with Japanese industry supported by the METI (Ministry of Economy, Trade and Industry) [6]. Based on this research, the JCAB (Japan Civil Aviation Bureau) plans to introduce UTM to enable BVLOS (Beyond Visual Line of Sight) flights of UAS over populated areas. Initially, operations of manned aircraft and UAS will be segregated mainly by flight altitude, with UAS flying below 150m AGL. To realize more safe and efficient airspace sharing among manned aircraft, UAS and eVTOL, JAXA has started research on intent sharing and coordination by integrating multiple operation systems including D-NET, UTM and the existing JCAB system (Fig. 6). In the pre-flight phase, the operation plans of existing manned aircraft, UAS and eVTOL will be coordinated and deconflicted. In the flight phase, the initial assumption is that mainly new entrants such as UAS and eVTOL will modify their routes dynamically to avoid any potential conflicts with the surrounding manned aircraft intent. For this purpose, it is important to accurately predict the flight trajectory, expected uncertainties and operation volume of manned aircraft flying under visual flight rules (VFR). JAXA is considering the mission characteristics to predict the trajectory of such flights [7]. For example, in the case of a reconnaissance mission, pilots usually fly tracking landmarks such as rivers or highways. Therefore, trajectories can be predicted utilizing the landmark information and pilot's control strategies. JAXA has already confirmed the feasibility of such approach in actual flight tests with its experimental helicopter. Trajectory prediction models were developed based on interviews with pilots and past experimental data analysis. In the latest series of tests conducted in January and February 2022, the dependency on the pilot, i.e. the human factor aspect was also investigated. Preliminary analysis of a sample flight segment indicated that the change of the pilot did not result in any significant increase in the deviation from the predicted trajectory, as illustrated in Fig.7. In general, pilot B was flying closer to the landmark, but the dispersions of flight tracks of both pilots did not show any significant differences, only a variation in the median. This is due to differences in the view angle used to construct the trajectory predictions, the angle was steeper for pilot B. Debriefings with

both pilots let us to believe that the position of the pilot in the cockpit dictates the median view angle, but this can be corrected if needed with alerts in flight. The flight tests also demonstrated that pilots can successfully use such alerts based on deviations from the predicted position to adjust their control. This situational awareness was provided through D-NET's tablet onboard (Fig. 8). Trajectory prediction and operation volume design will be further improved by analyzing the VFR flight trajectories collected by D-NET during the Olympic/Paralympic operations.

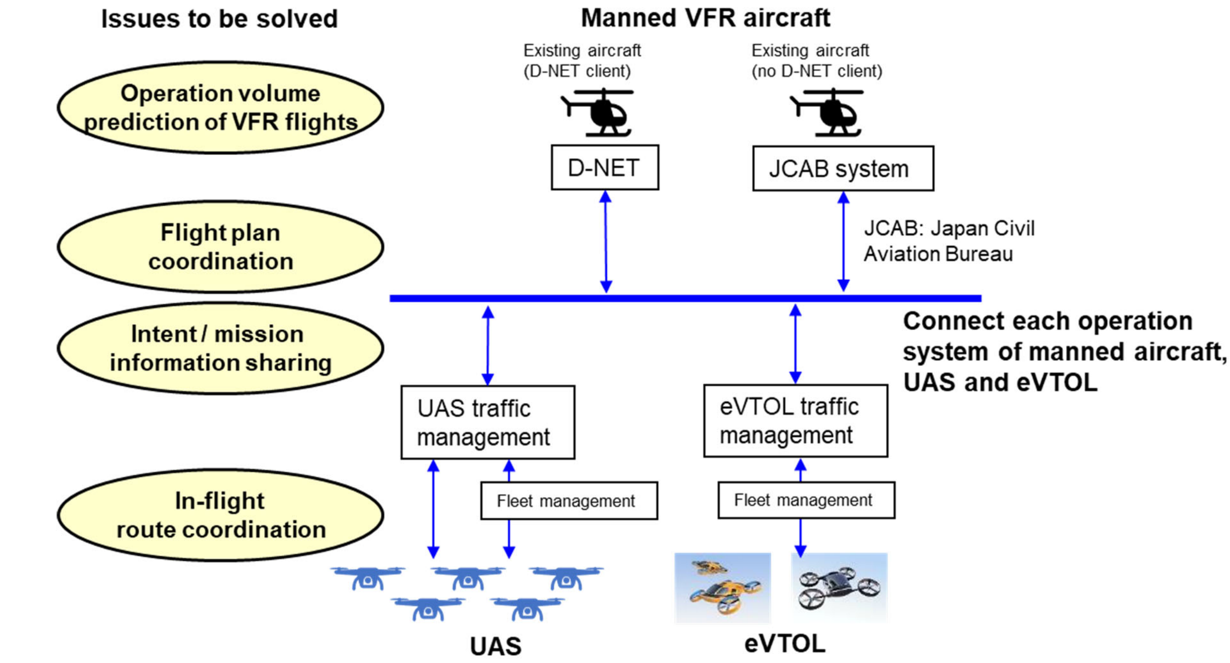

Fig. 6 Concept of integrated operation of manned aircraft, eVTOL and UAS.

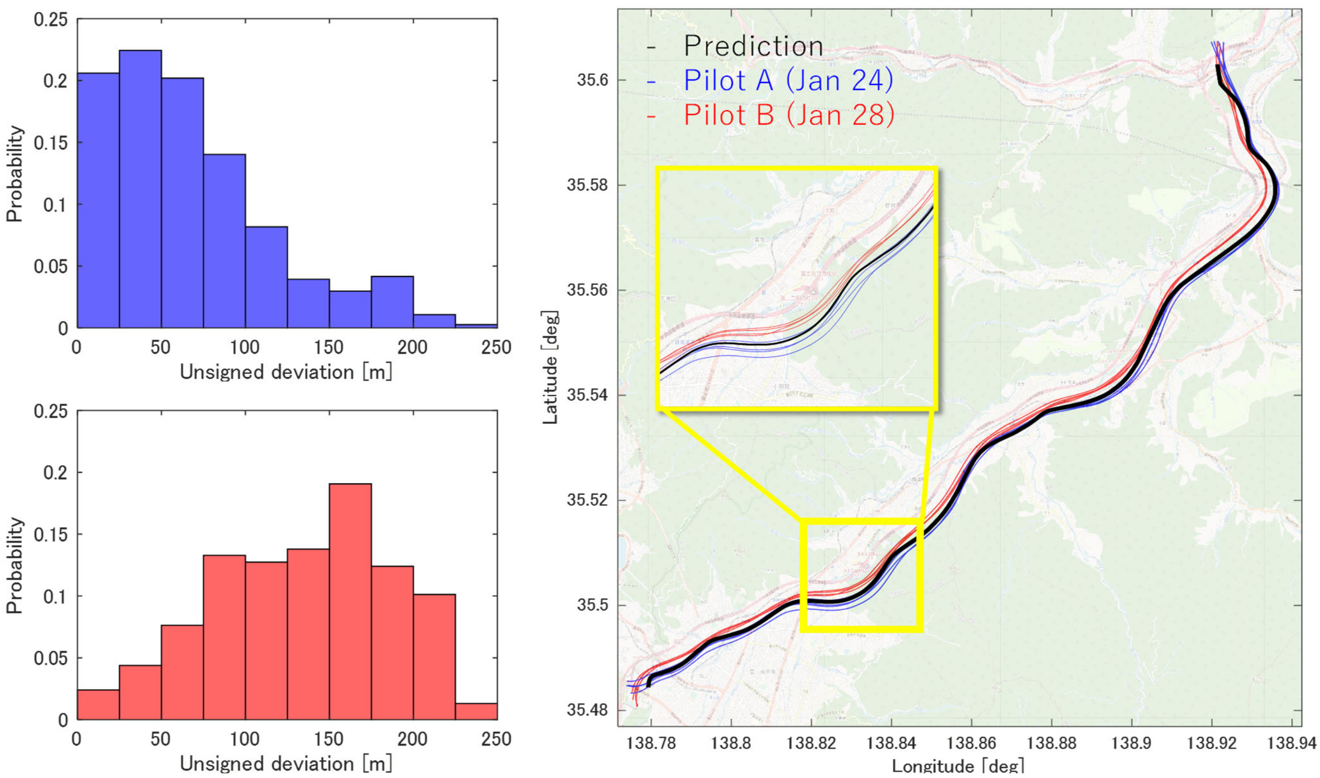

Fig. 7 Pilot's dependence and deviations from the predicted trajectory

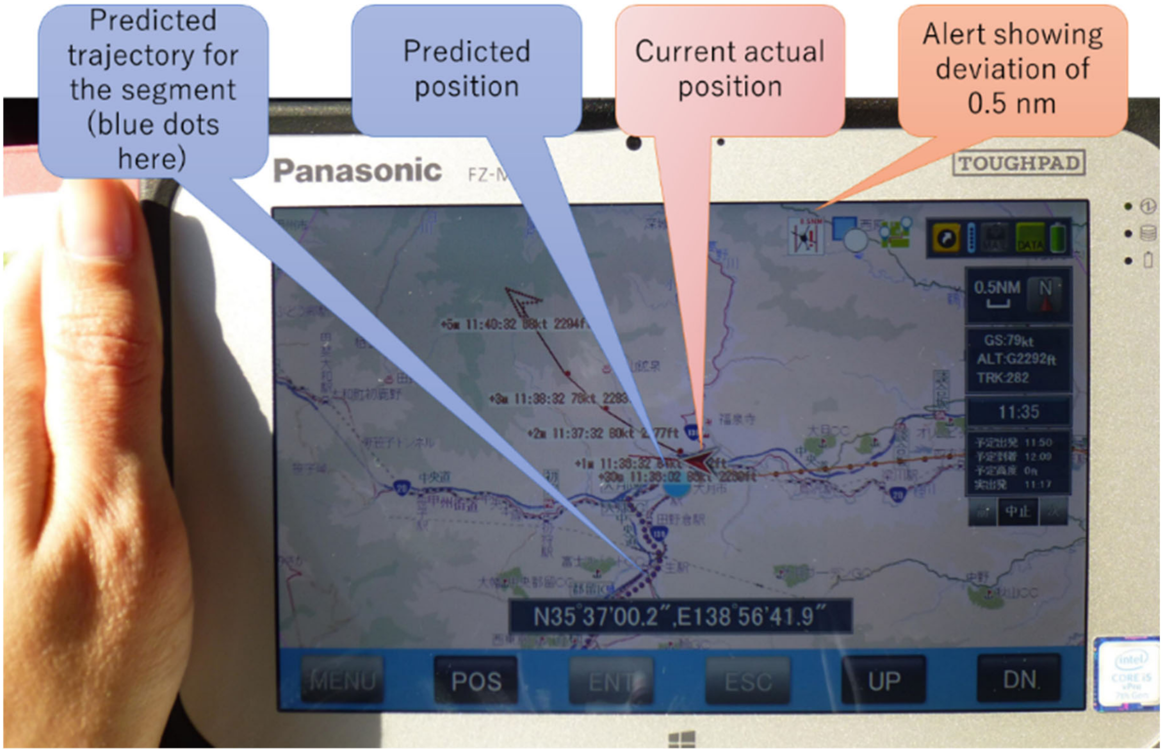

Fig. 8 D-NET onboard system showing the predicted and actual flight positions and deviation

- Mission information sharing for efficient operations: Flight deconfliction can be done at several stages, i.e. strategic, tactical and short-term detect and avoid. Although the primary purpose of flight deconfliction is safety, avoiding collision, operation efficiency should be also considered especially at strategic and tactical levels. Efficient flight intent sharing can resolve most conflicts, but it is limited by the large number of uncertainties, complicated procedures and potential lack of willingness or capability to share mission details. In order to bridge the gap between flight intent sharing benefits and operability, JAXA plans to develop mission information exchange format that defines necessary items to be included considering the both strategic and tactical flight plan coordination. As for the first trial of mission information sharing, JAXA connected D-NET with UTM to share mission information for disaster-relief mission. Figure 9 shows the flight demonstration at disaster drill in Japan. Once UAS finds a rescue-required person, the person's location information is sent to rescue helicopter via D-NET. When the helicopter approaches the mission area, UAS vacates the area according to the request from the helicopter via UTM and the helicopter safely conduct rescue mission. Mission information sharing between manned helicopter and UAS enabled the safe and efficient rescue mission.

4. Conclusion

This paper introduced applications, technological challenges and potential solutions of new entrants' integration in Japan based on JAXA's expertise acquired in disaster response technology research and development. The technical challenges faced by D-NET, such as surveillance, flight intent sharing and mission information sharing, are also common and valid for general UAS and eVTOL operations in low altitude airspace, not limited to disaster response, thus making lessons learnt relevant for broader UAM applications.

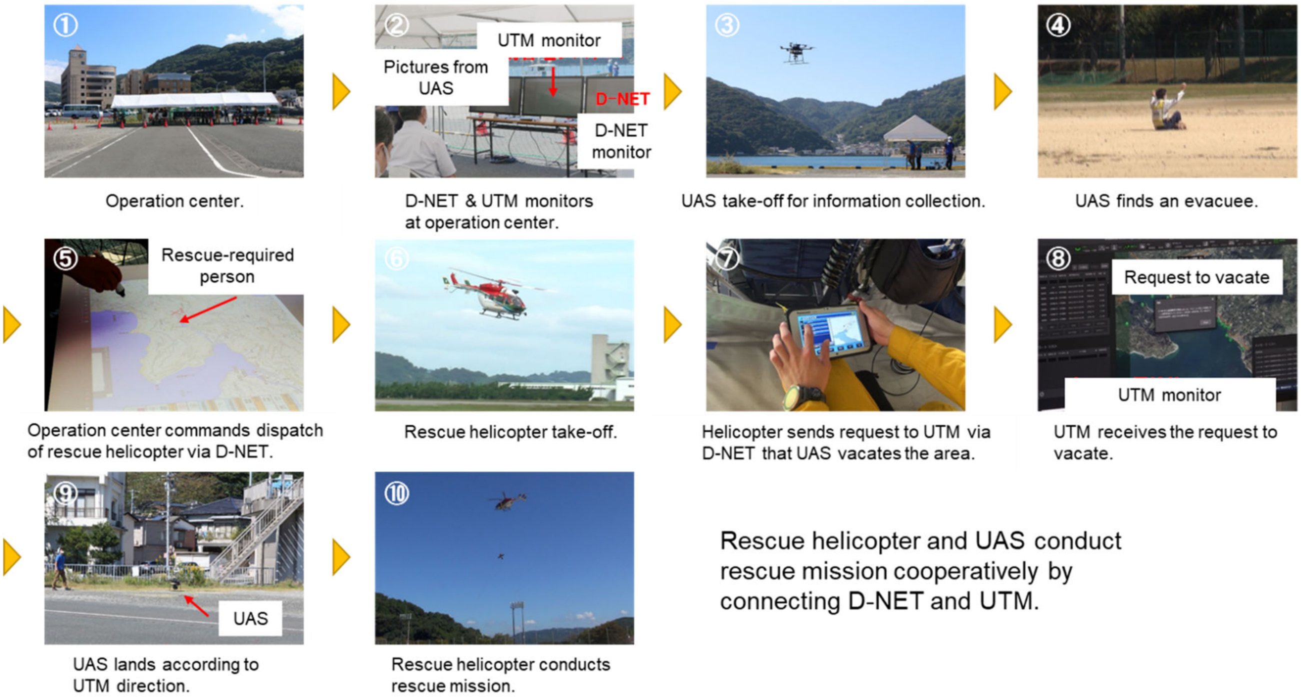

Fig. 9 Cooperative rescue mission of manned helicopter and UAS by connecting D-NET and UTM.

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6. Copyright Statement

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