Flight Demonstration for Information Sharing to Avoid Collisions between Small Unmanned Aerial Systems (sUASs) and Manned Helicopters*

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This paper describes our work building and testing a concept to share information among operators of manned aircraft and small unmanned aerial systems (sUASs) using the same low-altitude airspace to reduce collision risk, which is an urgent issue due to the rapid growth of sUASs use in many countries. Our concept is to share the positions of manned aircraft and sUASs on a web-based UAS Traffic Management (UTM) platform and provide alerts that give the operators of sUASs sufficient time to land the sUASs before a manned aircraft reaches the designated minimum airspace distance necessary for separation from the sUASs. The purpose of this paper and the flight demonstrations is to investigate the feasibility and problems in building such a platform. This paper also reports on the latest sUAS situations, including regulatory discussions, operations, the experimental environment, and the required regulatory arrangements.

Key Words: UAS, UTM, Flight Testing

1. Introduction

Small unmanned aerial systems (s/UASs) are becoming more and more necessary in various industries, such as media, agriculture, construction and delivery (Table 1). UASs are widely believed to bring huge economic and social benefits to such industries because they may replace costly or dangerous work in high places, like building inspections, as well as create new services by easing the access and use of low-altitude airspace. Therefore, the number of sUASs in the sky is forecast to increase dramatically in the coming years. In the U.S., for example, the Federal Aviation Administration (FAA) forecasts that total hobbyist sUASs will likely reach 3.5 million units by 2021 and total commercial sUASs will likely exceed 420,000 by 2021.1)

Mid-air collisions of sUAS with manned aircraft are a serious safety risk of sUAS operations, but the risk can be reduced by the management of airspace.2) Indeed, in many countries, the use of sUASs is allowed only in uncontrolled airspace and at low altitude in order to reduce the risk of mid-air collisions with manned aircraft. For example, in the U.S., sUAS operation is allowed up to 400 ft (about 122 m) above ground level, and in Japan, up to about 490 ft (150 m) above ground level. However, manned aircraft also fly in uncontrolled and low-altitude airspace.3)

While pilots of manned aircraft have the obligation of keeping watch over other aircraft and objects to avoid collisions, it is often difficult to recognize sUASs from manned aircraft.3) Operators of sUASs need to avoid manned aircraft because of the differences in maneuverability and airspace priority. However, considering the high speed of manned aircraft, a sUAS operator may not able to decide and act quick enough to maintain safe airspace separation from the manned aircraft.

This paper describes work done to build and test a concept to share information among operators of manned aircraft and sUASs using the same low-altitude airspace in order to support manned aircraft and sUASs so as to be seen by other operators. Our concept is to share the positions of manned aircraft and sUASs on a web-based UAS Traffic Management (UTM) platform, and to provide alerts to sUAS operators so that sUAS operators can make decisions and take action to maintain safe airspace separation and avoid collisions with manned aircraft. Such a platform to share information among different operators of manned aircraft flying under visual flight rules (VFR) and sUASs at low-altitude airspace has not yet been established. The purpose of this paper, then, is to investigate the feasibility and problems in building such a platform through flight demonstrations, especially using an Iridium satellite communication system to obtain aircraft position.

Table 1. Examples of sUAS applications.

| Segment      | Application examples                                      |
|--------------|----------------------------------------------------------|
| Agriculture  | Crop dusting, surveillance of harmful animals, precision agriculture |
| Delivery     | Medicines or daily necessities to isolated areas or urban areas |
| Disaster prevention | Searching, guarding, observation, delivery of goods, restoration of infrastructure, communication relay |
| Media        | Filming                                                  |
| Construction | Site survey, surveillance, replacement of manual work in high places, such as building inspections |
| Others       | Guarding houses and other property, replacement of manual work in high places, such as inspecting tall buildings |

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2. Background

2.1. Regulatory background

Japan is one of the countries where sUASs have been used commercially for a long time. Unmanned helicopters have been used for crop-dusting since the 1980s and, according to the Ministry of Agriculture, Forestry and Fisheries (MAFF), about 2,800 unmanned helicopters are used for crop dusting over 1.058 million hectares in Japan.\(^4\) However, regulations concerning use of sUASs did not exist until 2015. On April 22, 2015, a sUAS was found on the roof of the official residence of Prime Minister Shinzo Abe. On April 24, Shinzo Abe and his cabinet held the first sUAS conference among related government agencies and started discussions to regulate sUASs. In September 2015, Japan issued an amendment to the Civil Aeronautics Act and included sUASs in the scope of the Act.

An overview of the Act and the guidance can be summarized as follows: The use of sUASs is limited to daytime and within a visual line of sight (VLOS). In addition, sUASs are prohibited from flying close to populated areas and airports. Operation of a sUAS requires a distance of at least 30 m from people, buildings, and vehicles in Japan. The Japan Civil Aviation Bureau (JCAB) will permit sUAS operators to fly them under prescribed conditions when the operators can guarantee that the pilot is knowledgeable of the following: weather conditions, skills such as emergency maneuvers, fail-safe system of the sUAS in case of the loss of the global positioning system (GPS) being used, the links and batteries for the sUAS being used, and the organizational and operational systems.\(^5\)

Just after enforcement of the amended Act in December 2015 in Japan, a public-private council was held to discuss the appropriate environment for developing sUASs (see Nakamura and Kajikawa).\(^6\) One of the urgent issues discussed at the council was the collision risk between manned aircraft and sUASs.

In many countries, the use of sUASs is allowed only in uncontrolled airspace and at low altitudes in order to reduce the risk of mid-air collisions with manned aircraft. For example, in the U.S., sUAS operation is allowed up to 400 ft (about 122 m) above ground level, and in Japan, up to about 490 ft (150 m) above ground level. However, manned aircraft fly even in uncontrolled and low-altitude airspace. According to a survey conducted by the All Japan Air Transport and Service Association (AJATS) with their members, 150 aircraft fly 50% of their operation times, or about 70,000 hr a year, below 150 m.\(^3\) In general, manned aircraft fly below 150 m to deliver items, monitor power lines, and for crop-dusting and rescues.\(^7\) Since December 2015, when JCAB started to accept reports concerning sUAS incidents, there have been four reports from helicopter operators about sUASs that have flown as close as approximately 60 m to their helicopters during operation below 150 m. Reducing the risk of mid-air collisions of sUASs with manned aircraft is already an urgent issue. Responding to this situation, a study group was formed by JCAB and members from the council in November 2016 to consider collision risk among manned aircraft and sUASs.

2.2. Literature about collision risk between manned aircraft and sUASs

Research exists that analyzes and models the risk of mid-air collisions and structure safety barriers such as that by Simpson et al.,\(^2\) Clothier et al.,\(^8\) and Denney et al.\(^9\) In this literature, strategic conflict management, separation provisions, and collision avoidance are safety barriers used in combination to reduce the probability of mid-air collisions. These studies discuss the operation of sUASs in controlled airspace where air traffic services (ATS) take the main role of assuring separation and they discuss how to bring the same level of safety to currently controlled airspace.

There is also research about traffic management systems in low-altitude and uncontrolled airspace. Kopardekar et al.\(^10\) noted that the history of civil aviation has taught us that an appropriate level of organization is necessary for increasingly congested air traffic, even for sUASs. However, UTM is different from the human-centered traffic management of today’s controlled airspace for three main reasons. First, sUASs will be used at a higher density ratio than manned aircraft in the airspace, so automation of control is necessary. Second, onboard equipment is highly limited in size, weight and cost, and third, sUASs do not have a human pilot on board.\(^11\)

UTM research to accommodate the increase in the number of sUASs in low-altitude airspace and the expansion of operational situations, such as beyond VLOS (BVLOS) operations and flying over populated areas, have been active since early 2010. The National Aeronautics and Space Administration (NASA) has been leading a significant UTM research project and has been testing such technologies with a large number of partners from the public, academia, and private sectors.\(^12-15\) Under the Concept of Operations formulated by the NASA UTM, safety control is achieved through "a combination of airspace design, flight rules, operational procedures, ground-based automation systems, and vehicle capabilities to enable the safe use of the national airspace system."\(^11\) The European Aviation Safety Agency (EASA) has also recently highlighted the importance of UTM development for safe sUAS access to the airspace over populated areas.\(^16\)

A number of flight tests have been made with a “build-a-little-test-a-little” approach to enable scalability for anticipated future operations. Table 2 shows the objectives of tests with NASA UTM technical capability levels (TCL, Table 2). The overview of TCL 2 experiments, which finished in 2017, and tested basic UTM services, such as flight planning, flight monitoring, hazardous wind avoidance, and separation assurance, can be found in Aweiss et al.\(^11\)

This paper examines flight monitoring and separation assurance of the basic UTM services. Specifically, separation assurance is discussed as the separation between sUASs and manned aircraft in an uncontrolled airspace. Dao et al.,\(^13\) who evaluated the human factors of sUAS operation in a NASA UTM TCL 2 experiment, pointed out that data collec-
tion opportunities are needed to enable the development of effective UTM functions. Accordingly, this paper contributes to an extension of the discussion about the separation assurance functions of UTM to include manned aircraft in mutual information sharing.2

3. A Position Information Sharing Concept and Our Web-Based System

3.1. Overview of the concept

Currently, there is no standardized equipment to share information for both manned aircraft and sUASs to avoid mid-air collisions when flying below 150 m. Since the risk of such collisions is tangible, there is an urgent need to build a solution to reduce the risk. The concept of our web-based UTM platform, which provides notification through web-based software, is that operators of manned aircraft and sUASs flying in the same airspace can send the positional data of their aircraft to our flight database and receive the positional information of other aircraft. The system also provides a notice to advise sUAS operators to land or fly away from the area, and an alert to warn the operators involved that the airspace separation required between a manned aircraft and a sUAS is being violated. Based on this information, the operators can maintain separation. Our concept accommodates various ways of obtaining positional data, which makes choosing the easiest way to obtain this data even easier.

3.2. Our web-based system

The operators of sUASs use smart devices that serve as the ground control station (GCS) or are directly coupled with a GCS (Fig. 1).

An operator registers the name of the aircraft (ID) and type of aircraft at the website and selects whether it is in-flight or not and inputs the position of the aircraft. The input can be done either in the form of text data or by moving the icon of the operator’s aircraft on the map of the web browser (Fig. 2). If an operator sends the positional data as text, the operator needs to program his/her GCS to produce the positional data using heading angle, longitude, latitude and altitude. The software refers to the selected text periodically.
The positional data that the flight database records is as follows:
- Name of aircraft (ID)
- Type of aircraft
- Whether aircraft is in-flight or not
- Heading angle
- Longitude and latitude
- Altitude
- Time data received

The horizontal distance between a manned aircraft and a sUAS is calculated. The system shows that the separation between the manned aircraft and sUAS is being violated. The distance for sending a notice that advises sUAS operators to land or to fly away from the area, and an alert to warn the operators involved can be programmed differently based on the combination of type of aircraft depending on the required separation distance and the time required to execute the maneuver for separation after receiving the notice. Currently, there is no standard for the airspace separation requirement between manned aircraft and sUASs.\(^{17}\)

Low cost and ease of compliance are the advantages of our system. Presently, most sUASs are equipped with a camera. Therefore, a camera-based separating assurance system where each aircraft senses other aircraft can be an alternative method for increasing situation awareness and reducing the risk of mid-air collisions. However, the authors did not take this approach because such an approach only allows detection of other aircraft when there is no obstacle between the aircraft. Although the authors do not use a camera-based system, it can also be beneficial in solving the immediate risk of mid-air collisions. Mid-air collisions should be avoided under layers of safety barriers.\(^{18}\)

4. Demonstration Planning and System Packaging

To verify the effectiveness of the system using an alert for sUAS operators to land their sUASs when a manned aircraft is approaching their space, we conducted a flight demonstration. To simulate the possible situation where manned aircraft and a sUAS may get close enough for separation management, the demonstration was conducted utilizing the following scenario.

4.1. Demonstration scenario

Flight demonstrations with our web-based system were conducted in the Ushibuka district, Amakusa in Kumamoto Prefecture. The city of Amakusa is in the south of Japan, and is a major part of the Amakusa Islands, which is surrounded by ocean. Amakusa is connected to Kyushu Island by five bridges. However, because it takes about two and a half hours to get to the city of Kumamoto (i.e., the prefecture capital) by car, helicopters are often used for emergencies. Kumamoto Prefecture has one fire and emergency helicopter (FE-helicopter), an AS365NS Airbus helicopter nicknamed “Hibari,” and the Japanese Red Cross Kumamoto Hospital has one medical-service helicopter to cover the prefecture and surrounding areas. The medical-service helicopter can take a person from the city to the hospital in Kumamoto within an hour, while an ambulance requires two hours. In 2015, each of the helicopters flew to the city of Amakusa once every three days. Figure 3 uses stars to illustrate the off-site airfields for helicopters. There are 63 such airports. A helicopter may fly below 150 m in these areas at the time of emergency missions. The medical-service helicopter may also land at other places if necessary.

The authors created the following flight demonstration scenario: a person falls off a cliff and an emergency call is made. The Amakusa rescue team decides to call Hibari. The arrangement is made by the Amakusa Interjurisdictional South Fire Station (South Station). Until the FE-helicopter arrives at the hill where the person fell, the city rescue team uses a Phantom 4 (rescue sUAS) to find and monitor the person. Another sUAS, controlled by a hobby operator, is flying in the area. The rescue team and the team of South Station cannot see or communicate with the hobby operator from their positions, so that they cannot tell the hobby operator directly that a helicopter is approaching. Figure 4 shows the demonstration site. The slanted lines and shaded part represent the hill where the person fell.

In order to verify the effectiveness of the system, we investigated the airspace separation function of the system; that is, if the separation between Hibari and the sUASs can be main-
tained using the web-based system. To do that, we recorded the positional data and also when Hibari could be recognized by sound. Although it is not the main purpose of this paper, the demonstration also verifies the necessary verbal communication procedure for a rescue team when using a sUAS, where the various operations of Amakusa Interjurisdictional Center are also being conducted.

4.2. Aircraft used for the demonstration

The specifications for the FE-helicopter Hibari are given in Table 3.

The authors prepared two sUASs for the experiment, a DJI Phantom 4 and a self-built MicroKopter UAS. The Phantom 4 was selected because the city of Amakusa recently began using it. The MicroKopter (Hobby sUAS) was selected to reflect the variety of sUASs on the market. Table 4 shows the specifications for the sUASs.

4.3. System packaging

4.3.1. Position information acquisition

(1) Hibari

It is not easy to obtain real-time positioning and flight plans of manned helicopters. Manned aircraft flying under VFR are not always equipped with air traffic controller (ATC) transponders or an “Automatic Dependent Surveillance Broadcast Out (ADS-B Out),” which broadcasts the position information of the aircraft with a signal that can be picked up by any appropriate receiver. In Japan, for example, VFR aircraft that fly within 9 km from the departure airport are not required to submit their flight plans prior to taking off. Furthermore, if the flights are urgent, such as flights used for rescue purposes, the operators can file the flight plans after taking off. These VFR situations are similar in other countries and make it difficult to know where the VFR aircraft is going to fly or is flying.

At the time of the Great East Japan Earthquake on March 11, 2011, about 300 helicopters came to the quake-stricken area from all parts of the country.19) At that time, people experienced difficulty in efficiently, effectively and safely coordinating the rescue operations among helicopters from different rescue organizations. Because the importance of tracking the positions of helicopters is generally recognized by the Japanese government, since the earthquake, the Japan Aerospace Exploration Agency (JAXA) has been conducting research for a flight information-sharing network system for disaster-relief, named D-NET. D-NET uses the Iridium satellite communication system to connect ground stations with aircraft in real time. By sharing information of aircraft positions, collisions can be avoided and the optimization of missions among different teams with different aircraft can be accomplished. JAXA designed standard specifications for the terminal and subsequently, the fire department started to introduce D-NET technology into FE-helicopters operated by prefectures in Japan in 2014. As of 2016, 56 helicopters out of 76 aircraft are equipped with D-NET terminals.

In addition, there is another system for helicopter information sharing called FOSTER-GA/FOSTER-CoPilot, which was developed by Weathernews Inc. in Japan. Medical-service helicopters, which are owned by hospitals, are the main users of the system. According to Weathernews, 90% of the medical-service helicopters in Japan have been equipped with the Foster system20) as of June 2017. There were 52 medical-service helicopters in Japan as of March 2018. FOSTER-CoPilot is onboard the aircraft and sends GPS information using the Iridium satellite system. FOSTER-GA is the ground station and receives helicopter information with weather information so that the ground team can monitor and control the helicopter, and manage communications between the base hospital and other organizations related to a mission.21)

Hibari is equipped with D-NET so that the positional data can be obtained through the D-NET system. The GPS information from Hibari is sent to the D-NET server through the Iridium satellite communication system. The authors created a code to obtain the positional data and GPS timestamp displayed on the D-NET web system, save them into text data, and then run the code on a computer connected with the public Internet (Fig. 5).

Because using a cellular network on an aircraft is prohibited under the Radio Law in Japan, the crew of Hibari cannot use smart devices to send positional data and obtain the information of other aircraft. Therefore, the South Station team sent positional data obtained from the D-NET web system from a computer and monitored other aircraft using our web-based system. Information that appears on our system, such as a sUAS and alerts, were relayed to the Hibari crew verbally by radio telephony during the experiment (Fig. 5).

(2) The rescue sUAS position

Positional information is uploaded to the database via the ground control system. Different ground control stations are used for each UAS (Fig. 6).

The DJI Phantom 4, the rescue sUAS, has a GPS module on the airframe, and positional information obtained on the sUAS is sent to a proportional controller using the manufacturer’s original communication method. In addition, the pro-

| Manufacturer     | Airbus Helicopters | Airbus Helicopters |
|------------------|--------------------|--------------------|
| Aircraft type    | AS365N3            | AS365N3            |
| Registration number | JA15KM             | JA15KM             |
| Capacity         | 13 people          | 13 people          |
| Length           | 13.73 m            | 13.73 m            |
| Rotor diameter   | 11.94 m            | 11.94 m            |
| Height           | 4.06 m             | 4.06 m             |
| Empty weight     | 2,700 kg           | 2,700 kg           |
| Engine and engine type | 2×Safran Helicopter Engines Ariel 2C | 2×Safran Helicopter Engines Ariel 2C |
| Cruising speed   | 271 km/h           | 271 km/h           |
| Range            | 834 km             | 834 km             |

Table 3. Specifications for FE-helicopter Hibari.

| Manufacturer     | DJI                  | DJI                  |
|------------------|----------------------|----------------------|
| Aircraft type    | Phantom 4            | Phantom 4            |
| Weight           | 1,380 g              | 2,300 g              |
| Controller type  | DJI                  | DJI                  |
| Controller type  | Phantom 4 Transmitter | Phantom 4 Transmitter |

Table 4. The sUAS specifications.
Part 107 of the FAA recently introduced Title 14 Code of Federal Regulations for the commercial operation of sUASs and VLOS operation mandate a distance limited to a one-mile radius. Currently, operators of manned aircraft have expressed their fear of sUASs. If a sUAS comes into view, this may negatively impact the pilot of the manned aircraft in making a decision about what to do. In this experiment, the approximation of the minimum distance may affect the safety of the experiment, but not the overall objective of the experiment: whether or not our system can support sUAS operators in maintaining airspace separation, which is our overall research objective. Furthermore, for the safety of the experiment, the crew knew the sUAS operation scenario prior to the experiment so that they would not be surprised when they saw the sUAS.

Table 5 is the speed and height of Hibari provided by the Disaster and Fire Aviation Center of Kumamoto Prefecture for the purpose of designing the alert timing. This information is for reference only. The actual speed and height vary depending on various conditions, such as the weather, payload, and events on the ground. To enable a sUAS to land before Hibari reaches the minimum distance from the sUAS, the authors considered two factors; first, the time required for landing after recognizing the alert; and second, that the position reported through the D-NET system is not real-time data.

For the time needed for landing, the authors set two different times for the rescue sUAS and hobby sUAS. For the rescue sUAS, the operator should be able to use the sUAS as long as possible to conduct his/her mission. Moreover, the operator is supposed to be well trained and also communicate well with the teams managing the FE helicopter’s arrival. On the other hand, the skill of hobby operators varies. Therefore, the authors set 20 s and 80 s for landing, after which an alert is designed to go off when Hibari reaches 9 km from the hobby sUAS and 5 km from the rescue sUAS (Fig. 7).

The position reported through the D-NET system was intermittent and not in real-time. The authors were permitted to access the D-NET web-based service only twice before the experiment due to concerns about allowing the position of the FE helicopter to be known to people outside of the Center. The authors found that the position information was sent to the D-NET web service from Hibari with an adjustable, but still irregular, interval. The operator can choose the interval. The more frequently the data is sent, the higher the cost. Therefore, the authors arbitrarily set the minimum distance as 2 km for the experiment. One of the reasons for choosing this distance was that one mile, or about 1.8 km, can be considered the distance at which a sUAS is visible. This is because Part 107 of the FAA recently introduced Title 14 Code

### Table 5. Speed and height of Hibari for South Station operations.

| Distance from destination | ~3 km | 3 km–500 m | 500 m–|
|---------------------------|-------|-----------|-------|
| Speed                     | 130 kt (240 km/h) | 100 kt (185 km/h) | 57 kt (140 km/h) |
| Height                    | 1,500 ft (450 m)   | 1,000 ft (300 m)   | 500 ft (150 m)   |

### 4.3.2. Alert design

To design the alert timing, first the authors needed to determine the minimum allowable distance between a manned aircraft and a sUAS before separating them. No regulation or widely accepted distance required for separation currently exists. (17)

Therefore, the authors arbitrarily set the minimum distance as 2 km for the experiment. One of the reasons for choosing this distance was that one mile, or about 1.8 km, can be considered the distance at which a sUAS is visible. This is because Part 107 of the FAA recently introduced Title 14 Code...
the positional data. While the authors could not obtain the data to investigate the cause of the delay, it is assumed that most of the delay was due to the process used to send the data from the aircraft to the server via satellite.

We tried solving the infrequent interval problem by calculating the current position with the latest information of the aircraft’s speed and direction, referring to the time the information was updated to the D-NET system. Our system did not include the delay associated with the sending process from the aircraft to the D-NET server. Some people in the industry worry about making the FE helicopter position available to those who are not operators. Therefore, the authors have considered the delay problem in the design of the timing of the alert and used 30 s as the uncertainty because it was the maximum delay observed when we tested the system before the experiment.

It must be noted that the position of the sUAS that appeared on our system was also not in real-time. We assumed the speed of the sUAS as 4 m/s, and that it transmits data every 4 s. That is, the maximum position error due to data transfer is about 16 m. However, we didn’t include the potential positional error of the sUAS in the alert design for this paper.

4.4. Safety back-up for the experiment

To conduct the flight demonstrations safely, the authors built a party line with voice transceivers to be used among demonstration participants on the ground. Information about flight starts, completions on landing, and alerts were shared not only systemically, but also verbally through the transceiver as a backup. Additionally, although the alert is designed to go off at a time so that the operator can land the sUAS before Hibari reaches the minimum distance, Hibari stayed 600 m away from the South Station team until members could visually confirm that no sUASs were flying.

4.5. Other experimental conditions

Even though the Ushibuka district is not a heavily populated area, at the experimental site, possible situations for a sUAS to fly less than 30 m from people, cars, and the helicopter might have occurred. The authors applied for and received permission from the JCAB. The JCAB granted this permission only for when the observer or pilot stands between sUAS and people, cars, and the helicopter, and the helicopter has come to a complete stop.

To conduct this experiment, the authors had to discuss the situation with people who use the area daily. These days, people are sensitive to the operation of sUASs. Therefore, the authors and the Amakusa city government explained the experimental plan to the Japan Coast Guard, the Fishermen’s Cooperative Association, and neighborhood self-governing bodies.

Amakusa city officials also spoke with the school lunch center, which is located next to the South Station. During the experiment, the authors wanted to block the road, but the center needed to use the road at the same time for lunch delivery. We agreed to block the road when the center did not need to use it. We also built a party line among the people participating in the experiment to allow trucks to and from the center to use the road safely.

5. Results

The experiment was conducted from 14:00 to 15:30 on December 18, and Hibari flew to South Station two times. The major activities are listed in Table 6.

In this experiment, an alert on our system went off when the distance between Hibari and one of the two sUASs was less than a certain distance (Fig. 8). The operators of the sUASs made their sUAS land as soon as they received the alert. As shown in Table 6, at 14:30 and 14:46, the Hibari operator announced that it had reached 600 m, just after the hobby sUAS landed and before the rescue sUAS completed landing. The alert could not make the sUASs land before the distance to Hibari was less than 2 km.

Figure 9 shows the distance between Hibari and the sUASs. The gray dots show the distance estimated on the system based on the data of direction and speed received previously. Blue and black dots show the distance calculated based on the real-time position of Hibari. Hibari sent the positioning data with the time when the data was acquired. For example, the alert that Hibari had reached 5 km away from the rescue sUAS was based on the positional data received from the D-NET system at 14:29:57, but the positional data was acquired at 14:29:08 and sent to the D-NET server via satellite. On the other hand, the distance (gray dot) at the time

\[\text{Distance from sUAS (m)}\]

![Fig. 7. Alert timing design.](Fig. 7)

![Fig. 8. Alert of an approaching manned aircraft for a rescue using a sUAS.](Fig. 8)

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1 A distance of 600 m was arbitrarily set by the authors by referring to the Civil Aeronautics Act that sets the minimum safety altitude over populated area as 300 m higher than the top of the highest building within an area of a 600-m radius from the helicopter.
Table 6. Timeline of the experiments on December 18, 2016.

| Time from 14:00 | Activities | Notes |
|---------------|------------|-------|
| 00            | South Station requested that Hibari fly to South Station. | |
| 04            | The rescue sUAS team communicated with South Station about using the sUAS. | |
| 05            | The rescue sUAS took off to search for the person who fell off the cliff. | Arrival time was 14:30 instead of 14:25. The authors originally planned for a 14:30 arrival. → This difference changed the time the rescue sUAS took off because of its limited battery life. |
| 06            | The Hibari crew communicated the estimated arrival time to South Station. | The authors ordered the operator of the rescue sUAS to delay the timing of take-off. → The operator of the hobby sUAS misunderstood that the order was for him. However, the misunderstanding was recognized before he reacted. |
| 10            | The rescue sUAS team communicated with South Station that the rescue team was going to make the sUAS return to base for a battery change. | |
| 11            | The rescue sUAS returned for a battery change. | |
| 16            | The hobby sUAS took off. The South Station team communicated with the Hibari crew that the rescue sUAS had returned and the system recognized that one sUAS was flying. | |
| 20            | The rescue sUAS team communicated with South Station that the rescue sUAS was being relaunched, and the rescue sUAS took off again. | |
| 27            | The Hibari crew communicated to South Station that the helicopter was approaching the destination. | |
| 28            | An alert went off for the hobby sUAS (28'17''): Hibari was 9 km away on the system. | “We arrive in two minutes. Please make sure that all sUASs land and tell us about the wind status.” → The South Station team concentrated on informing the crew that two sUASs were still flying, but forgot to inform them of the wind status. The wind status was reported when the crew asked again. |
| 29            | The hobby sUAS landed (29'26''). South Station communicated the status of the sUASs to the Hibari crew. The sound of the Hibari was recognized (29'56''). An alert went off for the rescue sUAS (29'57''): Hibari was 5 km away on the system. | |
| 30            | The rescued sUAS landed (30'31''). The rescue sUAS team communicated the sUAS status to South Station. | “South Station confirmed that one sUAS landed. We asked them to tell us when they would arrive 600 m away from the station.” → The crew answered immediately that Hibari was 600 m away from South Station (30'13''). The rescue team retrieved the sUAS 20 s after landing. “South Station confirms that two sUASs have landed. Hibari, please come to South Station.” |
| 32            | Hibari landed. | |
| 37            | Hibari took off for the second training flight. | |
| 40            | Both sUASs are cleared for take-off. | |
| 41            | Both sUASs have started to take-off. | |
| 42            | South Station requested that Hibari fly to South Station. The rescue sUAS team communicated with South Station about sUAS status. | |
| 45            | An alert went off for the hobby sUAS (45'13''): Hibari is 9 km away. The hobby sUAS landed (45'52''). | “South Station requests Hibari to fly to the station. According to the system, two sUASs are flying. Please stop 600 m away when you approach.” The estimated time of Hibari’s arrival is within 210 s. |
| 46            | An alert went off for the rescue sUAS (46'04''): Hibari is 5 km away. The sound of Hibari was recognized (46'24''). The sUAS rescue team communicated with South Station about their status. The rescue sUAS landed (46'51''). | “Hibari is 600 m away from the destination. Please give us sUAS status (46'40'').” |
| 48            | Hibari landed. | |

of 14:29:08 was estimated based on Hibari’s information of the position, speed and direction obtained at 27'47''.

After the hobby sUAS operator received alerts, the sUAS landed in 69 s in the first experiment and 39 s in the second experiment. After the rescue sUAS operator received alerts, the sUAS landed in 34 s in the first experiment and 47 s in the second. While the hobby sUAS landed within the designated time (80 s), the rescue sUAS took 14 to 27 s longer than the designated time (20 s).

On the other hand, the Hibari crew announced that they had reached 600 m 116 and 87 s after the alert for the hobby sUAS went off for the first and second experiments, respectively, and 16 and 36 s after the alert for the rescue sUAS for the first and second experiments, respectively. While we cannot eliminate the possibility of inaccuracy at the announcement, Fig. 9 shows it highly probable that Hibari reached less than 2 km before the rescue sUAS landed. Because the hobby sUAS alert and rescue sUAS alert were designed to go off when Hibari was recognized as reaching 9 km and 5 km on the system, Hibari should have arrived at the 600 m mark 131 s and 71 s after the alert of 9 km and 5 km, respectively, according to the information in Table 3. The
time gap between the time from the alert to Hibari’s announcement of 600 m, 116 and 87 s for the hobby, and 15 and 36 s for the rescue, and the theoretical time from the alert to Hibari’s 600-m arrival is most likely due to Hibari’s position acquisition delay.

6. Discussion

6.1. Separation violation

The authors investigated why the alerts at 9 km and 5 km did not make the hobby sUAS and rescue sUAS land before Hibari was 2 km away from them. In the alert design process, the authors considered two factors: namely, the time for sUAS operators to land the aircraft after recognizing the alert; and two, the latency of the D-NET positional data.

The rescue sUAS team landed their aircraft while taking a longer time than the authors designed. It took a longer time to land because the rescue team did not make the sUAS land on the ground where the sUAS was flying, but had the sUAS fly back to the area where the rescue sUAS took off. We did not relay clearly to the operators where to land when the alert went off because the safety of the landing area depends on the situation. We should have clarified the procedure for an emergency landing. This is important not only for standardizing the time required for landing in the design of the alerts, but also for the safety of sUAS operation in general. However, the time required for landing will vary depending on the skill of the operator and the operating environment, so it is difficult to generalize the time in the alert design. A possible solution for effective alert timing is to use the assessment of an sUAS operator. Every time an operator starts a mission, the operator should announce the estimated time required to land for the mission during an emergency.

Regarding the latency of the D-NET positional data, at the designated time of landing, the authors added 30 s to cover the delay of position information acquisition on the D-NET system according to the information available before the experiment. Nonetheless, the authors found there was up to a 69-s delay with an average of 28.9 s.

Hibari’s position acquisition delay and the inadequate estimation of Hibari’s position did not allow the sUASs to land before Hibari reached the minimum airspace separation distance. The authors of this paper believe this inadequacy is more critical than the inadequacy of the landing time estimation for safe separation. In our concept, the operator of a sUAS refers to the position of other aircraft as well as preparation for the necessary maneuvering because a sUAS should avoid manned aircraft. While the sUAS operators can know the position error of their own sUASs and should know how long they need to land in such a circumstance, they cannot know the inadequacy of the position of a manned aircraft displayed on the system. While further investigation about latency, standardization of latency, or solutions to minimize latency are expected in our future research regarding alert designing, such investigation may take time and require certain costs for manned aircraft. Another way to design a safer alert in the short term is to let the operators of manned aircraft input how much delay their position may include until standardization. For example, although the authors input 30 s to observe the maximum delay, when we tested the system before the experiment, the Hibari pilot may have thought it would take more time, for example 70 s, for the data to be updated on the server for its route based on his/her experience. Then again, some operators might even input a time de-
may give way to great advancements in this domain if the operators of sUASs and manned aircraft. Accumulation of systems of detection and collision avoidance installed on the sUASs and manned aircraft. Accumulation and analysis of incident reports about near misses and collisions of manned aircraft and sUASs were also beneficial.

7. Conclusion

As the flying of sUASs has become more familiar to the public, and the number of sUASs in operation are expected to increase, information sharing among manned aircraft and sUAS operators will become even more important for safe airspace separation. While there is no standardized equipment for manned aircraft flying under VFR to send positional data or standardized methods to share information among manned aircraft and sUAS operators, the authors have developed a concept that accommodates various ways of obtaining positional data, requiring smart devices to send the data to a flight database and to obtain the information of other aircraft and alerts, which the authors believe has the benefit of easy implementation.

Through the flight experiments in this paper, we have learned that the system proposed enables the manned aircraft crew to feel safe. We also learned that such a system is necessary if more than 600 m should be kept between sUASs and manned aircrafts.
and manned aircraft. In this experiment, the sound of the Hibari only reached the operators near the destination of the Hibari 31 to 35 s before Hibari reported its arrival at 600 m from its destination.

On the other hand, in the flight experiments, our system did not make the operators of sUASs land before the manned aircraft reached the designed distance to ensure avoidance. The inadequate estimation of both of these factors had to be considered in the design of the alert, which caused such a result; specifically, the time required for the rescue sUAS to land and the latency of the positional data of Hibari.

The time required for a sUAS operator to land varies according to the skills of the sUAS operator and other operational circumstances. For professional rescue sUAS operators, an assessment of the time required to land is possible so that a self-declaration of landing time rather than a prescriptive landing time can be a solution to improving the design of the alert.

Positional data obtained via a satellite, such as the D-NET system, has a significant time delay. There are several options for obtaining the positional data of manned aircraft operating in uncontrolled airspace. However, some of the operators of both manned aircraft and sUASs may be reluctant to equip their aircraft with the tools to send real-time position and to participate in information sharing at their own expense because the frequent sending of real-time position increases cost. There are also security and privacy concerns. For example, a FE helicopter or helicopters used for law enforcement purposes will not want the public to know where they are flying, or for what purpose.

Standardization of uploading timing and frequency is necessary for effective alert design, but such standardization requires further research to determine the requirements. A system in which a manned aircraft operator announces the estimated latency in positional data is one of the solutions that can be implemented early and easily. The effect of the voluntary input of landing time and latency correction to the effectiveness of alerts is one of the goals of our future research.

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