

# DESIGN AND PRELIMINARY EVALUATION OF AN INTEGRATED AIRCRAFT OPERATION SYSTEM FOR DISASTER RELIEF

Adriana Andreeva-Mori, Keiji Kobayashi, Masato Shindo, Yoshinori Okuno

### Japan Aerospace Exploration Agency

**Keywords**: immediate post-disaster management, satellite imagery, preliminary information, optimal resource distribution

### Abstract

Japan is one of the most earthquake-prone countries in the world and aircraft from various organizations are involved in relief operations in the case of a large-scale disaster. Japan Aerospace Exploration Agency has been developing an integrated aircraft operation system D-NET2 to support disaster information acquisition, mission planning and decision making. D-NET2 combines manned and unmanned aircraft in an unprecedented endeavor to aid immediate disaster relief. The system consists of three main subsystemsinformation integration subsystem, optimal resource management subsystem and onboard mission support subsystem. The information integration subsystem substitutes the current practice of using analog tools such as radio and telephone voice communication and white boards to share information by digitalizing the process and making information accessible in real time regardless of the actual location of the user (on the ground or in the air). The optimal resource management subsystem assigns various missions such as search and rescue and supply delivery missions to manned and unmanned aircraft and spacecraft (satellites) for efficient relief operations. The onboard mission support system provides pilots and crews with humanmachine interface to enable safer and more efficient mission performance. This paper describes the designs of the entire D-NET2 and each subsystem. A twofold test method was *employed to verify the performance and identify* points of improvement in the system, namely disaster drill verification (field tests) and numerical simulation tests. Tests of preliminary version of the system showed that D-NET2 has sufficient functions and user-friendly interface to support disaster relief operations. Furthermore, the efficiency of the system was verified in numerical simulations proving that applying the system to immediate disaster relief can increase dramatically the number of rescued people.

### **1** Introduction

Large scale disasters cause enormous damage and require fast and efficient response. With Japan being one of the most earthquake-prone country in the world, the level of disaster preparedness is relatively high, but regardless of the precautions taken in city planning and construction, disaster response immediately after an earthquake remains crucial for minimizing the damages and casualties. Current post-disaster operations are human-centered. Recent technological advances, however, have opened the possibilities for a decision-support system which can optimize reconnaissance and disaster relief aircraft assignment.

This section presents the background of the research and the past disaster relief technology developed at Japan Aerospace Exploration Agency (JAXA).

### 1.1 Background

In the event of a large-scale disaster, aircraft play a major role in relief operations as ground access to disaster areas is often impossible due to damaged infrastructure. Once a disaster strikes, disaster relief headquarters and local disaster relief operation centers are formed, where information is gathered and relief missions are scheduled and dispatched. Disaster relief aircraft management is usually controlled by an aircraft operation center formed within the local disaster relief operation center. At present, the main information sources are telephone, fax and direct reports. The information is then shared on white boards and used by dispatchers to schedule and order reconnaissance and rescue missions. This basic flow varies with the scale and particular type of disaster, but the overall structure has remained unchanged.

Numerous issues in immediate disaster relief management has been identified after the Great Hanshin Earthquake, which hit Kobe area in January 1995. To cope with the enormous scale of the earthquake, helicopter from various organizations from all over Japan were deployed to the disaster area. At the time, there was no established system for collaboration between these organizations (for example, fire departments, medical service helicopters, selfdefense forces, etc.), and this considerably slowed down the relief process. This also caused mission duplication, i.e. more than one helicopters belonging to different organizations were assigned to the same rescue mission. Besides, it was revealed that the large number of rescue missions was beyond the handling capability of a human dispatcher, no matter how experienced and skillful they were. Some of the issues revealed during the operations in 1995 have been successfully solved, like the coordination of helicopters nationwide, but many remained even when the Great East Japan Earthquake hit in March 2011 (see Table 1).

 Table 1. Disaster relief issues addressed in the period

 between two major earthquakes in Japan

Issue	Great Hanshin Earthquake	1995-2011	Great East Japan Earthquake
Nationwide helicopter deployment coordination	Anticipated	Improved	Solved
Use of helicopters for EMS	Revealed	Improved	Solved
Efficient collaboration between organizations	Revealed	Not improved	Not solved
Response to wide area disaster	Unknown	-	Revealed
Management of large number of helicopters	Revealed	Not improved	Not solved
Systems for efficient refueling and maintenance	Revealed	Not improved	Improved
Duplicated or unnecessary mission assignment	Unknown	-	Revealed
Congestion of air-ground radio communication	Revealed	Not improved	Not solved
Operation in bad weather conditions	Revealed	Not improved	Not solved

Once again, it was shown that efficient relief operations in the immediate aftermath of a largescale disaster depend on fast and accurate data acquisition (search) and the ability to analyze these data so that they can be used to coordinate rescue efforts.

Relief efforts in the immediate aftermath of the Great East Japan Earthquake were also hindered by bad weather- rain brought down greatly the visibility and grounded helicopters relying on visual flights [1]. Furthermore, even though as many as 300 aircraft were involved in the relief operations at a point [2], there was a great difference in the progress of relief operations, i.e. regional gaps, depending on the particular location of the disaster area. In this research, the progress of disaster relief operations is measured by the parameter "Quality of Life" (QOL) [3] which expresses the post-disaster condition of a single area unit. Right after the disaster, QOL in all areas is 1, i.e. no information on condition and damages is available. For disaster response teams, this is the most critical condition possible. Once information has been collected and the rescue needs have been defined, the area is characterized by QOL=2. Only then can specific rescue be planned and executed (QOL=3). Recovery level when a certain level of routine life can be lead is described as OOL=4.



# Fig. 1. Progress of disaster relief operations in the aftermath of the Great East Japan Earthquake

Based on this metric and data collected and analyzed at JAXA, time history of the relief operations in the area hit by the Great East Japan

#### DESIGN AND PRELIMINARY EVALUATION OF AN INTEGRATED AIRCRAFT OPERATION SYSTEM FOR DISASTER RELIEF

Earthquake is generated and shown in Fig. 1. As seen from the figure, even though some areas have recovered to QOL=3, no information about others (QOL=1) was available. According to the current practice of disaster relief operations, no rescue mission is appointed unless there is information about the status of the areas [4], i.e. a rescue mission request. One of the main reasons for such a policy is the insufficient number of helicopters and the inability to allocate resources to low-probability missions.

To tackle the above issues, JAXA has started the research and development of an Integrated Aircraft Operation System for Disaster Relief (D-NET2). D-NET2 combines manned and unmanned aircraft, as well as satellites in order to achieve efficient relief operations, especially in large-scale disasters.

# 1.2 JAXA's Past Research on Disaster Relief Technology

To speed up data acquisition and reduce the errors during voice transmission, the predecessor of D-NET2, namely D-NET, has developed technology for real-time data transmission. D-NET details are out of the scope of this paper and can be found in [2], but here we present a brief overview to aid the reader's understanding of D-NET2. To provide real-time data transmission and rescue mission allocation, an on-board device was developed by JAXA. The main components are as follows, as shown in Fig. 2:

• Pilot display- A touch panel which allows data input, such as disaster information, by the pilot. It has been based on Electronic Flight Bags (EFB) available from DAC International [5]. The interface has been developed taking into account pilot, doctor and fire department personnel's feedback to assure user-friendliness and high efficiency.

• Assistant display- Has the same functions as the pilot display, but is meant to be operated by crew other than the pilot, usually in the back of the helicopter.

• Processor- Uses the aircraft on-board computer. Compared to computers used in everyday ground operations, it can be used in environment with various temperature and under various atmospheric pressure and oscillations, but as its computational power is relatively small, high-speed program coding is required.

• Transmission device- Data is transmitted by iridium satellite. Transmission is possible via a small antenna, but the data amount which can be transmitted is limited.

• Transmission antenna- attached so as to not to be affected by the main rotor.



Fig. 2. Onboard D-NET system

This real-time, accurate information from the rescue aircraft is transmitted via satellite to JAXA's server. This information is then accessible from ground sites such as local governments and national disaster relief headquarters. All parties share the same information and therefore can make informed decisions on aircraft operations and mission assignments.

D-NET solved the problem of information transmission delays to a great extent, but the relief operations in the aftermath of the Great East Japan Earthquake showed that a widescale disaster cannot be managed by helicopters only. Therefore, D-NET2 integrates unmanned and manned aircraft, as well as satellites to cope with the needs of a large-scale disaster.

# 1.3 Paper Scope and Organization

This paper provides an overview of the preliminary design and tests of D-NET2. The rest of this paper is organized as follows. D-NET2's overview and notional operation are presented in Section 2. JAXA's development and verification methods are discussed in subsection 2.2. D-NET2 system structure and its subsystems are explained in Section 3. The verification methods

and preliminary results are shown in Section 4. Section 5 concludes the paper.

# 2 Integrated Aircraft Operation System for Disaster Relief (D-NET2)- Overview

### 2.1 System Objectives

D-NET2 objective is to efficiently acquire data from sources such as satellites, helicopters and UAVs, analyze these data and provide an optimal resource allocation and flight trajectory plan, which can in turn be integrated in actual rescue operations. The system performance requirement is defined in respect to the number of remaining (unassigned and not yet executed) missions with a QOL of 1 or 2 72 hours after the disaster. The introduction of D-NET2 should reduce this number by 67% compared to the current disaster relief practices. In other words, generally speaking, there should be 67% less evacuees whose life is in danger waiting to be rescued by aircraft. D-NET2 is being developed as a decision-support system and, at this point, does not aim to be a fully autonomous system. The foreseen users are people involved in direct relief operation planning and execution, including decision-makers. high-level Research and development on D-NET2 started in 2013 and is scheduled to continue until 2018.

# 2.2 Operational Concept

D-NET2 is designed as a portable system for aircraft operation management in the immediate aftermath of a large-scale disaster. The operation concept is shown in Fig. 3.



Fig. 3. D-NET2 operations

The system has three main blocks: 1) data/information acquisition block, 2) optimal planning block and 3) operation execution block. The system employs three major types of vehicles as information sources: manned aircraft (mainly helicopters), unmanned aircraft and land-observation satellites. D-NET2 makes the most of each vehicle's characteristics and assigns optimal missions to each. Similar to current disaster relief operations, helicopters are responsible for providing detailed information on the damage levels and evacuees. They are also involved in evacuee transportation missions, including stranded evacuees and people who have managed to reach an evacuation area, but which has lately been endangered. Helicopters can also deliver medicines and other goods. Depending on the onboard equipment. helicopters transport patients (in particular, the medical service helicopters) from a hospital which has been stricken by the disaster to other safe areas/ hospitals.

Satellites, on the other hand, provide imagery over a wide disaster area even in the event of bad weather. Satellite imagery can be used to identify flooded areas [6], landslides and bridge damages, for example [7]. A candidate satellite is JAXA'S ALOS-2. D-NET2 uses the data provided by satellite imagery to aid disaster management authorities in their evaluation of the overall damages and to generate optimal manned aircraft assignment and trajectories.

Unmanned aerial systems (UAS) have already been used to monitor specific areas [8]. Furthermore, with the recent advances in UAV technology, broader applications such as supply delivery and continuous monitoring are likely to be realized in the near future. D-NET2 assigns data acquisition missions to UAS in order to spare resources from the manned aircraft fleet so that more helicopters can be assigned to rescue missions.

So far, the focus of research on UAS applications in disaster relief, however, has been on single or small number of aircraft operations. In the case of a large-scale disaster hundreds of aircraft are deployed and engaged in search and rescue mission. Therefore, the overall coordination and integration of all aircraft are just as important, if not more, as the individual

#### DESIGN AND PRELIMINARY EVALUATION OF AN INTEGRATED AIRCRAFT OPERATION SYSTEM FOR DISASTER RELIEF



Fig. 4. D-NET2 system structure

performance of any single vehicle. The complexity of a system to govern such offnominal operations is enormous, and to the best of our knowledge no such systems have been developed (excluding perhaps military applications, which data are not disclosed).

### 2.3 Research and Development Partners

Unlike nominal aircraft operations, disaster relief operations are characterized by a very large number of participants from various backgrounds and organizations. JAXA has been developing D-NET2 in order to be used in actual immediate relief planning and has partnered with government disaster-relief organizations on national and local levels, avionics manufacturers, software developers, academia and research institutes to ensure the system is developed in accordance with the demands of the end users.

# **3 System Design of D-NET2**

# 3.1 Overall System Design

D-NET2 is designed to interact with other external systems which will provide data to

support the disaster relief operations such as meteorological information system, satellites and satellite imagery procession systems. D-NET2 is build up by 3 subsystems- information integration subsystem (IISS), optimal resource management subsystem (ORMSS) and mission support subsystem. The conceptual design is shown in Fig.4. A brief introduction of the main three subsystems is given in this section.

# 3.2 Information Integration Subsystem (IISS)

As seen from Fig. 3, the system will integrate operation from satellites, manned and unmanned aircraft in direct search and rescue. Here, an example of satellite observation integration is presented. The system allows users to view disaster information such as fires and landslides together with flooding information obtained through satellite imagery. ALOS-2, JAXA's earth observation satellite, is a potential candidate for the system. ALOS-2 can conduct observation in spotlight, strip map or scan synthetic aperture radar modes over a wide area [9]. Besides, observations are possible at night and in bad weather, so in this respect it excels helicopter observation capabilities. IISS allows input/output of observation data to aircraft (manned and unmanned). For example, flooded areas can be defined as polygons and input manually on the ground. IISS holds data on the available aircraft, as well as real-time information on their position. Since D-NET2 is aimed to serve large-scale disaster relief operations, IMSS should be able to handle big data of approximately 1000 aircraft.

Unmanned aircraft can not only provide an important addition to the limited number of manned aircraft, but also conduct observations of dangerous areas (e.g. nuclear power plants, volcanic areas, etc.). Depending on the type of UAS, continuous observation of up to 72 hours is also possible. The relatively low cost and easy operation is also an advantage. At present, UAS main missions will be reconnaissance, and the implementation of this function in the IMSS is still ongoing.

# 3.3 Optimal Resource Management Subsystem (ORMSS)

Prior to designing the optimal resource management subsystem (ORMSS), search and rescue flow should be modeled. The model build here and shown in Fig. 5 is based on comments of disaster relief planning personnel and those involved in direct search and rescue operations. so it reflects reality accurately. The boxed grey, red and yellow numbers represent recovery level, varying from 1 (no observation/reconnaissance vet) to 3 (rescue completed), as defined earlier in Fig. 1. ORMSS implements various algorithms at each stage to ensure both efficient and userfriendly solutions. The first stage (blue) is the search one- aircraft fly over the disaster area to collect information on the damages and locations where people are waiting to be evacuated. At this stage, the system's output includes optimal aircraft assignments and trajectories. The second stage (green) is responsible for optimal rescue mission aircraft assignment.



Fig. 5. Model of the search and rescue process

One of the main questions which the ORMSS needs to answer is how to distribute the limited available resources (aircraft) to search and rescue missions. A single aircraft can do either a search or a rescue mission at the same time. In the beginning, less or none information about the disaster area is available, so our original assumption was that more aircraft should be assigned to search, and as data piles up more aircraft should be assigned to rescue to speed up the evacuation. This concept is shown in Fig. 6.



The optimization should result in a flight plan for the entire aircraft fleet. A conceptual image of the optimization result is shown in Fig. 7. As seen from the figure, night operations should be assigned only to aircraft with the appropriate equipment, while other aircraft need



Fig. 7. Conceptual optimal aircraft mission assignment and flight schedule

The reconnaissance optimization problem has been modeled as a grid world exploration problem and a hybrid genetic-algorithm based method was developed and applied [10]. At present, there are two potential candidates for the rescue optimization algorithm- a hybrid greedyparticle swarm optimization algorithm [11] and a layered optimization approach, which breaks down the complicated disaster relief operation

#### DESIGN AND PRELIMINARY EVALUATION OF AN INTEGRATED AIRCRAFT OPERATION SYSTEM FOR DISASTER RELIEF

management problem into three subproblemsevacuee flow planning (network flow problem), general aircraft resource distribution (weighted assignment problem) and aircraft mission assignment and flight scheduling (constraint scheduling). Further tests will be conducted to establish which algorithm is more suitable for D-NET2.

# 3.4 Onboard Mission Support Subsystem (OMSS)

There are several mission support subsystems, each with its own functional requirements and design parameters. Here, in the interest of space, only one such system is presented. The development of the human-machine interface (HMI) has been ongoing since the development of D-NET onboard system, shown earlier. Work continued and now research has and development of a fully portable D-NET onboard system is also in progress. Such a portability is required as various agencies such as fire departments, and self-defense forces are involved in disaster relief operations, and since the system does not require the installation of any devices prior to the relief operations, it will therefore be suitable for aircraft which nominal missions do not allow them to disclose their location. In other words, the portable system will be available for aircraft which do not have D-NET onboard. Human-machine interface is aimed at providing accurate real-time disaster information to the pilot and rescue personnel onboard. At present, the developed software supports transmission of information from other aircraft (this part of the subsystem is available as a commercial product) and research on transferring satellite imagery information and information from UAVs is ongoing.

The hardware components of the fully portable HMI subsystem are shown in Fig. 8. On the left is the satellite transmission component and in the upper right corner one can see the digital antenna, both of which make the transmission subsystem. In the lower left corner is the display which touch screen also enables input on pilot's behalf. These three components, together with the necessary cables connecting them weigh a total of 3,600 g. The HMI subsystem, portable or not, is developed at JAXA and once a certain technological maturity is achieved, technology is transferred to a partner in order to proceed with industrialization.



Fig. 8. Fully portable onboard system

# **4 Preliminary Evaluation**

The test and verification process adopted by D-NET2 is twofold. First, JAXA has been participating in disaster drills organized by governmental organizations to test the usability of the support systems, interface and gain feedback on the functions available in D-NET2. In the case of a large-scale disaster, however, hundreds of aircraft are involved in the relief efforts, and gathering such a large number of aircraft for real-environment verification is implausible. Instead, simulation tests with scenarios based on real-disaster relief data from the Great East Japan Earthquake and predictions of the Nankai Earthquake are conducted. In the simulation, data on aircraft equipment and executable relief missions, as well as realistic operational constraints such as refuel bases and flight range are introduced to make the verification as close to the real environment as accounts for the possible. This second verification method.

# **4.1 Evaluation in Disaster Drills**

D-NET2 is designed as a decision-support system to be used in direct search and rescue, so function verification in disaster drills in a key component in the project. This section presents a brief overview of current disaster relief practice in order to aid the reader's understanding of the disaster drills evaluation methods and results of D-NET 2 discussed below.

### 4.1.1 Current Disaster Relief Practice

At present, in the case of a major disaster, disaster relief headquarters as well as local disaster relief operational centers are formed where representatives of the organizations taking part in the relief operation would gather. Information on the type and scale of damage and evacuees is obtained via telephone, for example, and is made available to all people at a certain site through white boards. On the white board, the progress of each aircraft is also tracked to a certain extent, but only when feedback from the aircraft has reached the base, i.e. in most cases when the aircraft has returned back to the base or has completed a mission. Information from the aircraft is transmitted to the base via voice transmitter mainly so errors are common, too.

Mission assignments are also humancentered. The time a rescue mission request has been received is written on the whiteboard. The initial information usually includes only the departure hospital, and the helicopter operation headquarters start searching for a hospital which can admit the patient (evacuee). Next, a helicopter is assigned, but only after the necessary fuel and time are calculated. Usually, little information is available on the progress of the rescue mission and only once it is completed does the operational team get feedback and crosses is off the board (Fig. 9).



Fig. 9. Mission assignment and progress at a disaster drill (September, 2015)

# 4.1.2 Disaster Drill Evaluation Results

The main goal of the disaster drill field tests of D-NET2 are to evaluate the human interface of the system and verify the usability and sufficiency of its functions.

JAXA has been working on a prototype of the IMSS and tested its preliminary version in a large-scale disaster drill on Sep 1, 2015. The IMSS visualizes flooded areas based on data and analysis of satellite imagery. It also includes other information such as hospital and ground infrastructure status, for example. Disaster relief personnel with experience in search and rescue operation planning evaluated the system and commented that satellite imagery helped them grasp the big picture of the damages and thus plan their further actions efficiently.



Flooded areas based on satellite imagery (ALOS-2). The data is analyzed and presented as a polygon.

Fig. 10. IMSS's screenshot. Information from various sources is combined for thorough understanding of the damages and better rescue mission assignment

Information on flooded areas obtained based on the analysis of ALOS-2 satellite imagery is shown in blue on the right in Fig. 10.



Fig. 11. Disaster information input through an interactive projector (Chiba Prefecture, Sep 1, 2015)

Flooded areas shown in green have been input manually through an interactive projector (see Fig. 11). The concept mimics current disaster relief practices, where everyone is gathered around a table and shares the available information with the help of a paper-based map. This process is digitalized in D-NET2.

Another unique characteristic of the system is that it can create and send observation requests to a satellite in order to obtain satellite images of the disaster area. This is an unprecedented endeavor to actively include satellites in immediate disaster relief search operations. The function was tested in a disaster drill in August 2014. The observation request area is shown in green in Fig. 12. The area shown in orange is the actual approved satellite observation area plan.



Fig. 12. Information integration subsystem (satellite imagery request)

Observation requests are made no later than an hour before the satellite passes over the disaster area. The team in charge of the satellite operation considers all requests and plans for the most appropriate observation. The disaster management, on the other hand, can then send aircraft to areas not covered by satellite observation to acquire data on the entire disaster area efficiently without duplicating search efforts.

In the disaster drills, feedback on the functions of D-NET2 was also obtained. It was confirmed that providing advisory information on the aircraft trajectory and overlaying it with disaster information aids the decision-making processes in an efficient manned. More detailed quantitative evaluation is scheduled for 2016 and 2017.

# **4.2 Evaluation in Simulation**

### 4.2.1 Simulation Assumptions

In order to evaluate the performance of D-NET2 is a large-scale disaster, we ran numerical simulations based on data from the Great East Japan Earthquake and Tsunami from March 11, 2011. The evaluation was based on the time necessary to complete the rescue. A search priority was introduced to account for high-risk areas which are likely to have evacuees. Mission assignment based on "prediction" and "weighing" the disaster areas is a unique approach taken in D-NET2. Aircraft were modeled based on data of disaster-relief helicopters available in Japan.

### 4.2.2 Simulation Results

A sample simulation results under the assumptions presented above is shown in Fig. 13. The simulations evaluates the number of people rescued by aircraft in the immediate disasterrelief of the Great East Japan Earthquake. The circles show the data on rescues history from 0 hours to 84 hours after the disaster hit. Simulation on the rescue missions and time histories of aircraft missions were based on these data and the results are shown in the purple bold line in Fig. 13. The orange bold line shows the preliminary simulation results of D-NET2 optimization, including satellite imagery. The dotted lines indicate the number of survivors in both the baseline and optimization case. As defined by the system requirement of D-NET2, the optimization goal was to reduce the number of people waiting rescue by 67% compared to the current disaster relief practices in the first 72 hours right after the disaster. As seen from the figure, with D-NET2 all rescue missions are completed within 48 hours after the disaster, a performance which exceeds the requirement.

Please note that the results presented here are based on a preliminary version of the "layerbased algorithm" discussed in Section 3.3. Details on some of the specific optimization algorithms and large-scale simulation results can be found in papers published previously by the authors [11], [10].



Fig. 13. Sample numerical simulation results for search and rescue.

### **5** Conclusions

This paper presented the system requirements and design of the "Integrated Aircraft Operation System for Disaster Relief (D-NET2)," which consist of three subsystems: the information management subsystem, the optimal resource management subsystem, and the onboard mission support subsystem. The system concept and preliminary version were verified in disaster drills where valuable feedback was obtained from direct participants in relief operations. The large-scale disaster simulations of relief operations based on real disaster scenarios showed that with D-NET the number of people rescued by relief aircraft increases dramatically and 48 hours after the disasters no evacuees anticipated rescue and so the system requirements are fully satisfied.

Work on the research and development of D-NET2 will continue until 2018 when it is to enter practical use. More disaster drill verification tests are planned for finalizing the functions and interface of the subsystems and their overall interaction in order to provide efficient and safe relief operations.

### References

- A. T. et al., "Anaylsis of Aircraft Operations during the Great East Japan Earthquake (in Japanese)," 2012. [Online]. Available: http://library.jsce.or.jp/jsce/open/00039/201211\_n o46/pdf/111.pdf.
- Y. Okuno, K. Kobayashi and H. Ishii, "Development of a Helicopter Operations Management System for Disaster Relief

Missions," *Journal of the American Helicopter Society*, vol. 61, no. 1, pp. 1-9, 2016.

- T. Togawa, et al., "Evacuation, Post-disaster Reconstruction and Improvement," [Online]. Available: http://www.urban.env.nagoyau.ac.jp/sustain/paper/2011/kokusai/11k\_togawa1. pdf. [Accessed 14 6 2016].
- [4] L. Kawahara, Nine Days (in Japanese), Tokyo: Gentosha, 2012.
- [5] "DAC International," [Online]. Available: http://www.dacint.com/. [Accessed 21 10 2013].
- [6] J. Gomi, "Supporting Disaster Management with Space Applications," [Online]. Available: http://global.jaxa.jp/article/special/antidisaster/go mi\_e.html. [Accessed 14 6 2016].
- [7] A. Andreeva-Mori, K. Kobayashi and M. Shindo, "Evaluation of Satellite Imagery Integration in Optimal Aircraft Operation Planning for Disaster Relief," in *ICAS*, St.Petersburg, Russia, 2014.
- [8] D. Kubo and et al., "Development of experimental small UAV equipped with cellular phone data link system," *ICAS Proceedings*, 2006.
- [9] "ALOS Research and Application Project," JAXA, [online]. Available: http://www.eorc.jaxa.jp/ALOS/en/index.htm. [Accessed 20 7 2013].
- [10] A. Andreeva-Mori, K. Kobayashi, M. Shindo and Y. Okuno, "Optimal Aircraft Assignment in Immediate Post-disaster Reconnaissance," *APISAT*, 2015.
- [11] A. Andreeva-Mori, K. Kobayashi and M. Shindo, "Andreeva-Mori, Adriana, Keiji Particle Swarm Optimization/Greedy-Search Algorithm for Helicopter Mission Assignment in Disaster Relief," *Journal of Aerospace Information Systems*, vol. 12, no. 10, pp. 646-660, 2015.

# 8 Contact Author Email Address

The contact author Adriana Andreeva-Mori can be reached at the email address below: andreevamori.adriana@jaxa.jp

### **Copyright Statement**

The authors confirm that they, and/or their company or organization, hold copyright on all of the original material included in this paper. The authors also confirm that they have obtained permission, from the copyright holder of any third party material included in this paper, to publish it as part of their paper. The authors confirm that they give permission, or have obtained permission from the copyright holder of this paper, for the publication and distribution of this paper as part of the ICAS proceedings or as individual off-prints from the proceedings.