APPLICATION PLAN OF NEXT-GENERATION OPERATION SYSTEM TO DISASTER RELIEF HELICOPTERS

Keiji Kobayashi
Japan Aero Space Technology (working for JAXA)

Yoshinori Okuno and Kohei Funabiki
Japan Aerospace Exploration Agency (JAXA)
Mitaka, Tokyo, Japan

Abstract

Over 6,000 people were killed in the great Hanshin-Awaji earthquake in 1995. Helicopters were deployed for various activities during the rescue and relief operations, the first time they had been used on such a large scale in Japan, and many problems were revealed. Although various researches have since been carried out on disaster relief helicopter operations, several technical issues still remain to be addressed, such as increasing all-weather capability and establishing a system of operations that can handle over a hundred helicopters in a restricted area safely and efficiently. The Japan Aerospace Exploration Agency (JAXA) has been developing next-generation systems to support aircraft operations, such as a 3D pilot guidance system using a "tunnel-in-the-sky" display, a GPS/INS hybrid navigation system, and a data link system. This paper introduces these technologies and describes a plan to develop an operation management system for disaster relief helicopters by applying data link technologies, as well as the results of a preliminary simulation study of an airborne sequencing and separation assurance system applied to high-density traffic during disaster relief operations.

Abbreviations

ADS   Automatic Dependent Surveillance
ATC   Air Traffic Control
CDTI   Cockpit Display of Traffic Information
CPDLC Controller Pilot Data Link Communication
EMS   Emergency Medical Service
IFR   Instrument Flight Rules
ILS   Instrument Landing System
IMC   Instrument Meteorological Conditions
APV   Approach with Vertical guidance
MFD   Multi-Function Display
MSAS   MTSAT Satellite-based Augmentation System
MTSAT Multi-functional Transport SATellite
SBAS   Satellite-Based Augmentation System
UAT   Universal Access Transceiver
VFR   Visual Flight Rules
VMC   Visual Meteorological Conditions

Introduction

In Japan, the effectiveness of helicopters for disaster relief has gradually been recognized since the 1995 great Hanshin-Awaji earthquake. Figure 1 shows the number of emergency support helicopters operated by regional government administrations and the number of emergency medical service (EMS), rescue, and firefighting missions flown each year. The number of helicopters increased rapidly after
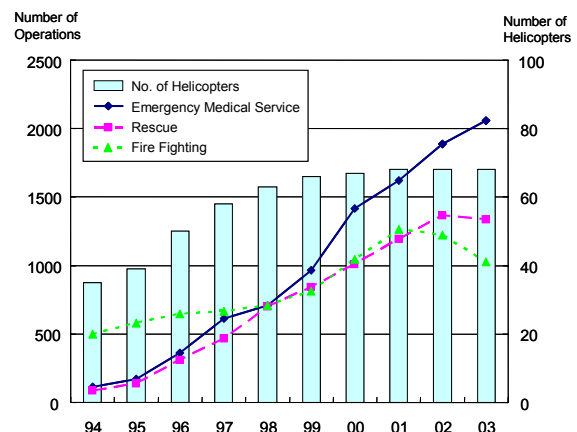

Figure 1 Number of the regional government emergency support helicopters and their operations.

1995, then stopped in 2000 after they had been introduced in almost all prefectures in Japan. The number of rescue and firefighting missions flown annually continued to increase until 2002, while the number of EMS flights is still increasing. The increase in the number of missions is mainly due to the following two reasons.

1. Fire regulations were revised in March 1998, and role of emergency support helicopters was clearly defined.
2. The Fire Defense Agency produced dispatch criteria guidelines for emergency support helicopters in June 2000.

When a large disaster occurs, it is anticipated that helicopters operated by many organizations will concentrate in the stricken area. Table 1 shows the number of the helicopters available for disaster relief operations in Japan. Note that this does not include commercial helicopters, which would also be deployed.

Figure 2 shows the concept of disaster relief operations. Operating bases, especially major bases such as airports, will become very crowded as they will be used not only for rescue operations but also for the transportation of relief supplies and for aircraft refuelling and maintenance.

Figure 3 shows the number of helicopter flights during relief activities for the Hanshin-Awaji earthquake in 1995 and the Niigata Chuetsu earthquake in 2004. It can be seen that the number of flights decreased considerably on the third day after the earthquake in 2004 and on the fifth day after the earthquake in 1995. These were due to bad weather conditions such as poor visibility. In a stricken area, roads and communication networks are extensively damaged and many areas become isolated. It is very important to fly missions such as reconnaissance or transportation of relief supplies to such areas immediately, even in bad weather. It is also necessary to transfer helicopters to the stricken area even in bad weather, especially during the early stages of relief operation. In these situations, it is also important to assure flight safety to prevent secondary disasters.

Table 1 Number of helicopters related to disaster relief operations in Japan (as of Mar 2005).

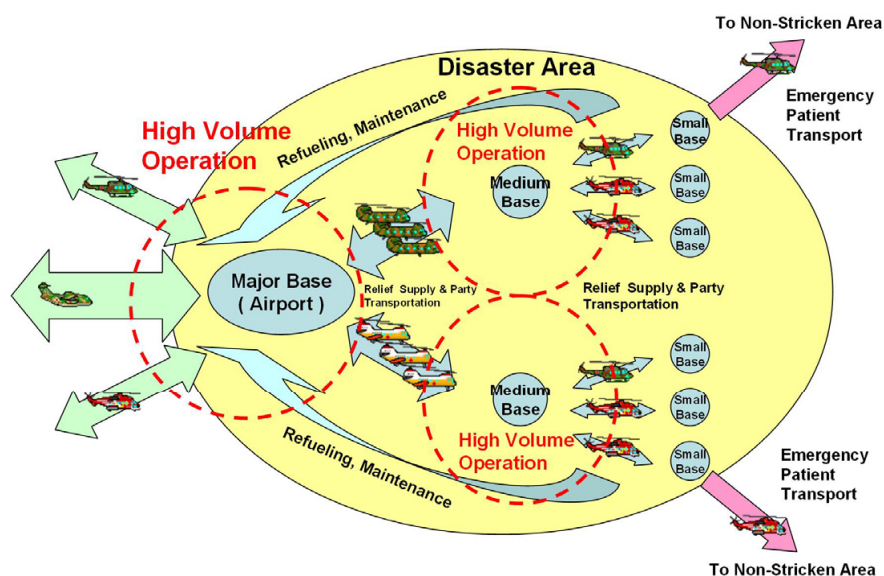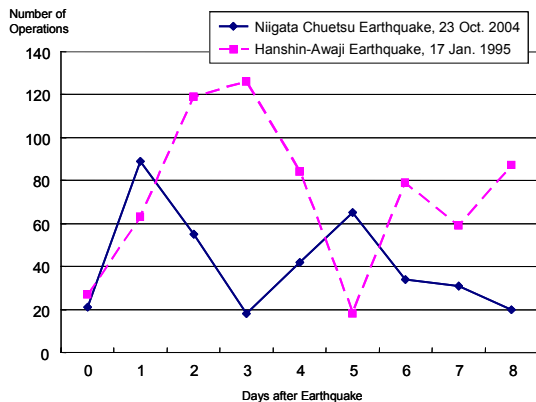| Operator	No. of Helicopters
Regional Governments (Fire Department)	69
Japan Self-Defense Force	660
Japan Coast Guard	46
Police	95
Doctor Helicopter (Air Ambulance)	9
Total	879

Figure 2 Concept of disaster relief operation.

Figure 3 Number of helicopter operations in two major earthquakes occurred in 1995 and 2004.

Not only the major airport serving a region, but regional or small airfields may also be pressed into service for relief operations. Such small airports, the majority without radar or ILS, and some even lacking a control tower, may be required to accept as much traffic as possible, even in instrument meteorological conditions (IMC). An airborne sequencing and separation assurance system would be useful to support such operations. Satellite navigation enhanced by a satellite-based augmentation system (SBAS), which enables APV (approach with vertical guidance), and a data link system such as ADS-B (Automatic Dependent Surveillance-Broadcast) and a satellite-based communication system, would be sufficient equipment and infrastructure for such a system.

Noise has also been found to be a problem during relief operations. During the Hanshin-Awaji earthquake, helicopter noise sometimes prevented rescuers from hearing victims trapped under destroyed buildings. After that, the establishment of "silent time" in stricken areas, that is no-flight times and areas with flight restrictions, was considered. Also, there is a problem of noise affecting adjacent non-stricken areas due to the large number of helicopters flying into and out of the stricken area over a long period.

Considering the above, the main issues that need to be addressed can be summarized as follows:

1. Flight restrictions due to bad weather or night conditions.

2. Insufficient measures to prevent secondary disasters, such as collision avoidance.
3. Lack of an information network system for managing operations.
4. Insufficient noise reduction measures.

Japan Aerospace Exploration Agency (JAXA) proposes the application of the next-generation technologies to disaster relief helicopter operations to address the above issues. Our goals are,

1. To realize an all-weather operational capability without ground-based support systems such as ILS, using satellite-based navigation and communication systems and an integrated pilot interface system.
2. To establish a network system utilizing data link technologies to allow information to be shared between helicopters and ground bases.
3. To develop high density approach and landing technologies to realize safe and efficient helicopter operations without ground control.

JAXA Research Activities

Next-generation Operating System

JAXA and the Electronic Navigation Research Institute (ENRI) of Japan have been conducting a research program called NOCTARN (New Operational Concept using Three-dimensional Adaptable Route Navigation) aimed at developing and demonstrating an aircraft operations concept that can enhance the capacity and operational efficiency of airports while reducing the noise impact on communities, focusing on regional airports and small airplanes and helicopters, by using precisely-defined trajectories which are shared between aircraft and air traffic control (ATC) (Ref. 1).

The NOCTARN on-board system automatically initiates communication with the aerodrome controller's ground station using a radio data link. Once communication is established, the position of the aircraft is displayed on the controller's ATC workstation and on multifunction cockpit displays (MFD) of other NOCTARN-equipped aircraft operating in the aerodrome control zone. After

receiving information on the runway in use, the pilot selects an approach route for the assigned runway using the MFD and a request for the route is sent to the controller by the data link. If the controller approves the requested route, it is assigned to the aircraft. Otherwise, the controller will offer an alternative route, again using the data link. The pilot then proceeds to fly along the assigned trajectory to the runway by following a perspective image of the route displayed on the MFD.

The NOCTARN research program includes the development of the following technologies.

1. Data link protocol integrating CPDLC (Controller Pilot Data Link Communication) and ADS-B functions.
2. Trajectory description protocol suitable for bandwidth-limited data links.
3. Pilot display integrating a 3-dimensional "Tunnel-in-the-Sky" guidance display, CPDLC console, CDTI (Cockpit Display of Traffic Information) and weather information (Fig. 4).
4. ATC workstation with trajectory-based CPDLC capability and route advisory function based on ground noise estimation.
5. Flight test and simulation environment based on HLA (High Level Architecture).

The operations concept has been demonstrated with an integrated prototype system by flight tests involving multiple aircraft in 2004 (Fig. 5).

GPS/INS Hybrid Navigation System

JAXA has been developing a GPS/INS hybrid navigation system called GAIA (GPS Aided Inertial-navigation Avionics) which can provide accurate and continuous navigation data without ground-based navigation aids (Ref. 2). This technology is being applied to a MEMS (Micro Electro Mechanical System) GPS/INS (Fig. 6) so that the size, weight, and cost are significantly reduced to meet the requirements of helicopter operators. MSAS, an SBAS service using the MTSAT satellite which was successfully launched in February 2005, will be started within a few years, and GAIA is being modified to utilize the MSAS functions.

Noise Abatement Approach Technology

JAXA has been studying the technology to allow aircraft to use 3-dimensional noise abatement approach paths to minimize the noise impact to the ground (Ref. 3). A real-time ground noise estimation model has been developed that considers the influences of aircraft location, flight conditions, wind conditions, and geographical characteristics. This model is applied to the NOCTARN ATC terminals and also to the pilot display, which shows a contour map of estimated ground noise level (Fig. 7), so that the pilot can avoid flying over noise-sensitive areas such as densely populated areas and especially facilities such as hospitals and schools.

Application Plans

In order to apply the above next-generation technologies to the disaster relief helicopter operations, the following two plans are being considered.

Figure 4 NOCTARN integrated display.

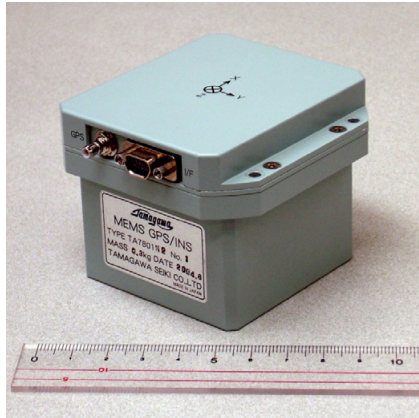Figure 5 JAXA's research helicopter MuPAL-ε and research airplane MuPAL-α.

Figure 6 Micro-GAIA (MEMS-GPS/INS).

Figure 7 Real-time ground noise display.

1. Development of a standardized information network system utilizing data link technologies.
2. Traffic simulation of disaster relief operations and application of NOCTARN technologies to realize safe and efficient high density operations.

These plans are described in detail below.

Integrated Information Network System

When a large disaster occurs in an urban area, it is expected that several hundred helicopters will take part in relief operations. It is important to prevent secondary disasters such as collisions, and since different organizations such as the fire department, police, and Self-Defense Force will take part, it is important that aircraft and related agencies share the same information in order to implement smooth and effective operations. Figure 8 shows the concept of a integrated information network system for disaster relief operation management. This system consists of three elements.

1. Airborne data link system based on VHF/UHF or satellite-based communication.
2. Ground network system based on the public Internet.
3. Operation management system including databases of available aircraft and ground facilities.

The benefits of this system are as follows:

On the helicopters

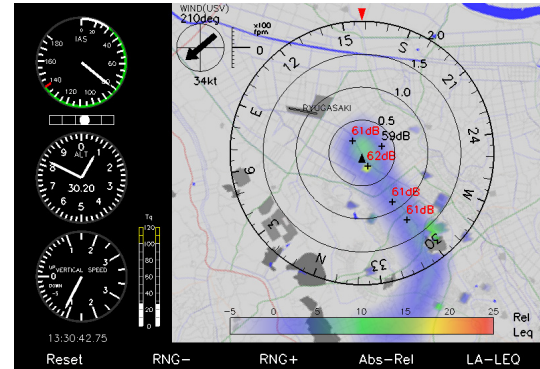1. A cockpit display of traffic information showing the positions of other helicopters operating in and around the area will increase pilot traffic awareness and reduce the probability of collisions.
2. Pilots will be able to obtain information on ground facilities such as heliports and medical facilities.
3. Pilots will be able to avoid flying over noise sensitive areas such as hospitals and schools, and obtain information on "silent time" restrictions.

In the stricken area

1. The operations center will be able to manage helicopters in a unified manner regardless of their operating agencies.
2. Using the available aircraft database, the operations center will be able to assign missions to each helicopter according to its performance and equipment.
3. It will be easy to determine whether ground facilities are exceeding their capacity.

Out of the stricken area

1. Operation centers will be able to provide logistical support, such as arrangement of relief supplies or additional helicopters, in a more timely and efficient manner.
2. Medical teams at hospitals will be able to monitor the activities of EMS helicopters to coordinate medical support. It may not always be possible for helicopters to land near a hospital to which casualties are being transferred. In this case, it will be necessary to find a landing point where ambulances can pick up incoming casualties
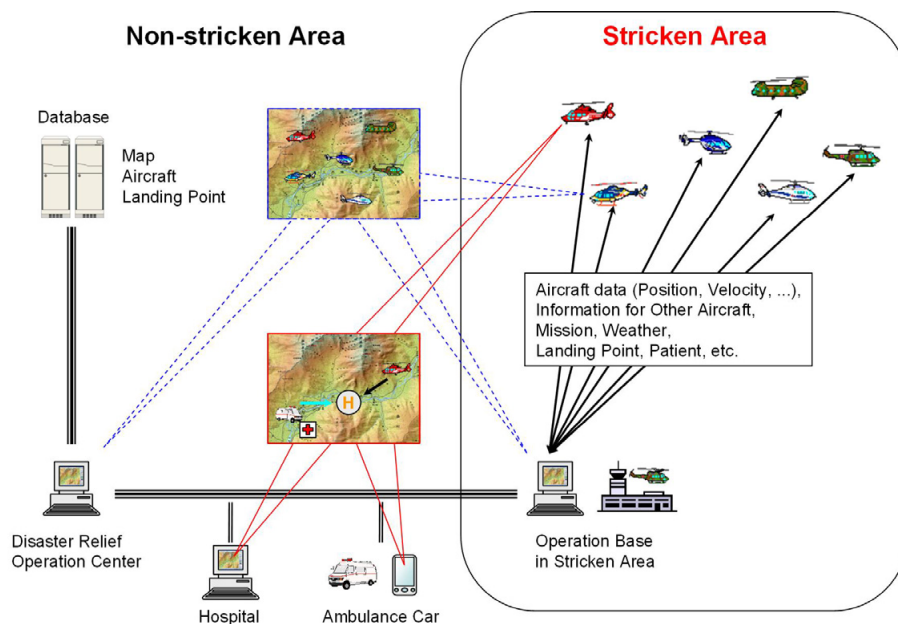
Figure 8 Concept of information network system for disaster relief aircraft management.

transferred by helicopter. If the network system is able to be linked to ambulances, for example using a PDA (Personal Digital Assistant) terminal, coordination for this will be facilitated.

Development Plan

In Japan, three data link systems are currently developed that can be used by helicopters. The first was developed by Pioneer Navicom Inc. based on the Iridium satellite communication system, and is currently in operational service. The second was developed by Kawasaki Heavy Industries, Ltd. (KHI) and Furuno Electric Co., Ltd. based on a VHF TDMA (time division multiple access) data link system (Ref. 4). The third is NOCTARN, which is based on a UHF TDMA data link similar to the KHI/Furuno system but using a different frequency band. However, because each of these systems is designed to a different standard, they cannot be integrated at present, and this will hinder widespread deployment. JAXA proposes a two-phase project to develop a standardized information network that will use the existing data link systems as sub-networks to solve this problem.

Phase 1 (2005 - 2006)

The goals of Phase 1 are as follows:

1. Study the requirements of a network system to integrate information from each data link system, and develop communication protocols.
2. Evaluate the effectiveness of a standardized information network system by conducting flight tests.
3. Identify the issues involved when these systems are used in disaster relief operations.

Figure 9 shows the concept of Phase 1. During Phase 1, the following items will be considered.

1. The on-board equipment of each data link system should be usable without any modification to minimize the test and certification cost and time.
2. Ground stations on each data link system are modified to adapt them to the integrated network environment.
3. Design and develop an "Integrated Operation Management System" using Geographic Information System (GIS) software along with a database system.

Phase 1 will be started soon. Development of the network system is scheduled in 2005 and flight test evaluation is scheduled in 2006.

Phase 2 (2007 -)

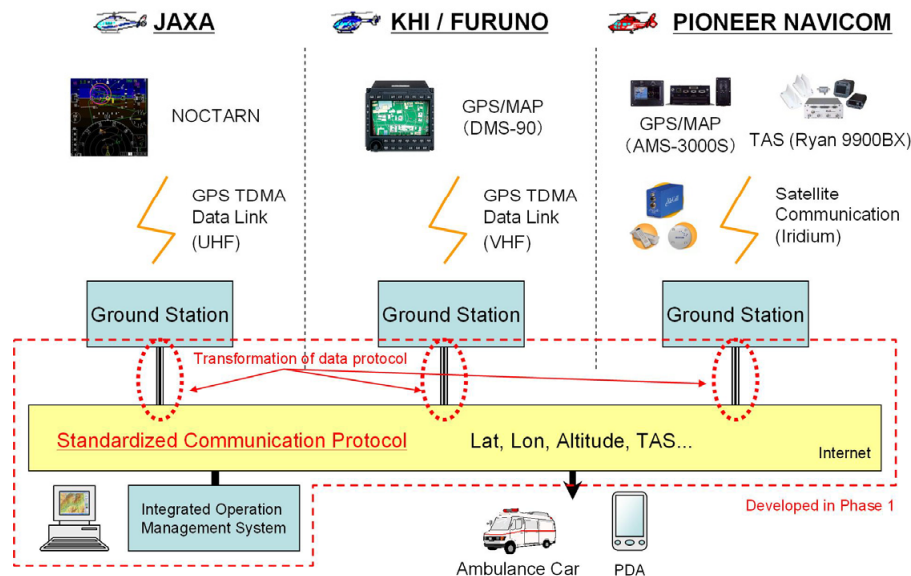The goal of Phase 2 is to develop a practical

Figure 9 Concept of Phase 1 integration of existing data link systems.

wide-use model of the data link system. In order to construct the Phase 2 system, we will consider the following.

1. Design the integrated data link system according to Phase 1 results.
2. Develop devices for helicopters, which must be small, lightweight and low-cost.

Flight evaluation of a satellite-based communication system using JAXA's Engineering Test Satellite ETS-VIII is also scheduled in 2007.

Traffic Simulation of Relief Operation

On the 23 October 2004, a major earthquake (Chuetsu earthquake) struck the Niigata area of Japan resulting in 36 fatalities, more than 2,000 persons being injured and the destruction of more than 8,000 houses and buildings. On the day after the earthquake, Niigata International Airport, which is located near the disaster area, accepted a huge amount of traffic that was several times greater than usual, and was operating almost at its capacity limit. As the first step to explore the possibility of applying the NOCTARN system to high-density traffic with a large proportion of helicopters, as may occurs during disaster relief operations, a preliminary simulation study was carried out for Niigata Airport scenario in Chuetsu earthquake relief operation (Ref. 5).

Simulation Scenario

A separation assurance and sequencing concept was prototyped based on NOCTARN, which is characterized by a 4D trajectory generation algorithm that minimizes technical flight error by taking into account the current wind and aircraft performance. Trajectory information is shared between aircraft and ground controllers using selected CPDLC-like protocols added to conventional broadcast mode ADS-B messages. Trajectory-based separation assurance and sequencing algorithms assuming both towered and non-towered operations have been implemented. Several trajectories are designed a priori for each approach and are stored in a database. The separation assurance algorithm then selects or proposes one of the trajectories for the designated approach while checking for conflicts with the trajectories of other aircraft received by data link. Once a trajectory has been selected, speed is used to assure separation. In this experiment, the system selects the shortest available conflict-free trajectory. Conflict detection proceeds as follows: The system first compares the ownship's trajectory with those of other aircraft to check whether a conflict exists. When another aircraft might intrude into the ownship's volume of protection, the system identifies this as a possible conflict. In this study, threshold of

longitudinal separation is 90 sec, horizontal separation is1.5 nm and vertical separation is 400ft.

Merging traffic flows with different speeds results in a degradation of throughput. This can be avoided by segregating different aircraft types by assigning them separate trajectories, and then merging them at the short final straight leg. However, the curved approaches that result may induce greater pilot workload, especially with manually flown small aircraft or helicopters, even if integrated flight guidance is provided. We therefore propose an "Overlapped Approach Concept" (Fig. 10) in which trajectories with different airspeeds are merged by altering the flight path angle to ensure vertical separation if there is insufficient horizontal separation. To realize the Overlapped Approach, a shorter separation ahead of helicopters should be allowed. As a nominal approach and landing procedure, a helicopter starts to decelerate shortly before landing so that its speed will be zero at the landing point. This is considered to provide additional buffer space in front of the helicopter.

The traffic is categorized into three types for convenience: (H) helicopter, (T) transport, and (G) general aviation. Type-H and type-G aircraft traffic operating with the NOCTARN system were treated as IFR, although they would be VFR in normal operations. Basic trajectories for type-H and type-G traffic were designed based on published VFR traffic patterns and approach procedures, assuming APV approaches. As an exception, to evaluate the Overlapped Approach Concept, the nominal approach path of type-H aircraft was set at 6 degrees,
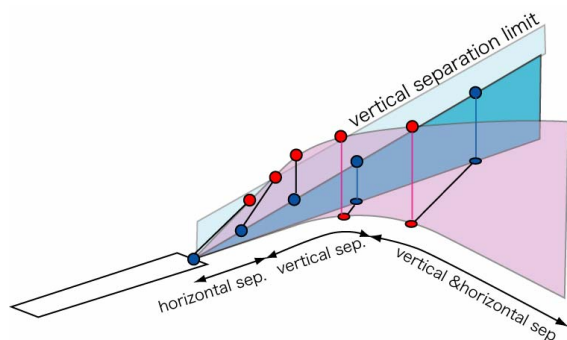
which exceeds the current standard for APV approaches. Each type of aircraft entered the scenario from a different assigned waypoint; TAIHEI for type-H aircraft, KAMEDA for type-G aircraft and OKESA for type-T aircraft as shown in Fig. 11. Aircraft were assumed to be spaced at least by 90 sec at the point of traffic generation. Aircraft in the scenario were generated randomly, based on the parameters of aircraft type ratio (e.g. H 70% : G 10% : T 20%) and traffic density. Traffic density was set by assigning an average traffic generation rate, and aircraft entered the scenario at intervals of the average value of 120 ±30 seconds. For each basic trajectory, a set of trajectory variations were pre-designed with a range of lengths 30-sec increments ("pitch") up to 360 sec in no-wind conditions.

Simulation Results and Discussion

Figure 12 compares two types of separation at the landing point: 3-deg approach path (nominal approach) and 6-deg helicopter approach path with reduced separation ahead of helicopters (overlapped approach). Permitting overlapped approaches reduced the elapsed time for type-H traffic by 140 sec, and also reduced the landing interval. The results indicate that the introduction of an Overlapped Approach Concept may increase runway throughput.

Although preliminary, a series of simulations of
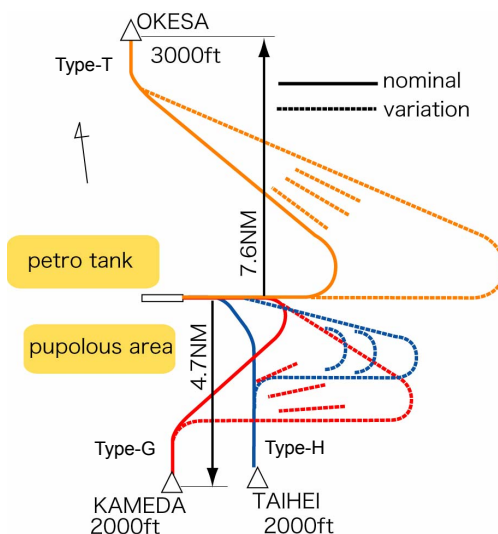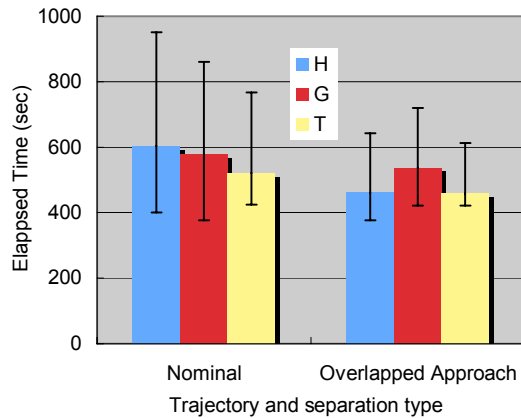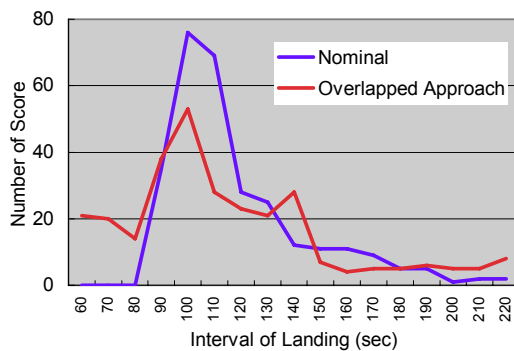

Figure 10 Overlap Approach Concept.

Figure 11 Simulation scenario traffic patterns.

(a) Elapsed time

(b) Landing interval

Figure 12 Example of simulation results.

disaster relief traffic varying the traffic type ratio, traffic density and airborne sequencing parameters gave significant insights into the nature of the traffic situation observed when major disasters occur. In the course of the simulation trials, other parameters such as the holding pattern size were also found to be influential. Efforts will be made to identify such parameters to further clarify the nature of the traffic and the system's characteristics.

Future Work

As the next step of this simulation research, the effects of wind and realistic flight technical errors will be taken into account. A method to enhance the throughput of helicopters in traffic situations with higher speed jet transport and prioritization algorithms for EMS helicopter operations will also be developed and integrated into the simulation. Measurement of flight technical error and pilot workload will be carried out using a CDTI as well as with a guidance display.

Conclusions

This paper introduced next-generation helicopter operating technologies currently being researched in JAXA, with emphasis on their application to disaster relief operations. The frequency of large earthquakes in Japan has been increasing in recent years, and the application of aerospace technologies to disaster relief is therefore one of JAXA's most important duties.

References

1) Funabiki, K., IIjima, T. and Nojima, T., "Evaluation of a Trajectory-based Operations Concept: Airborne Aspect," Proceedings of 22nd Digital Avionics Systems Conference, Oct. 2003.
2) Tomita, H., Harigae, M., Kokue, K., and Shiozawa, Y., "GPS-Aided Inertial Navigation Avionics (GAIA) Integrated with MSAS and Maritime DGPS Beacon," Proceedings of ION GNSS 2004, Dec. 2004.
3) Ishii, H., Gomi, H. and Okuno, Y., "Flight Tests of Helicopter Noise Abatement Operations," Proceedings of 31st European Rotorcraft Forum, Sep. 2005.
4) Kurita, K., Tomoyasu, K. and, Kobayashi, H., "Overview of the Operational Control and Information System for EMS helicopter," Proceeding of AHS International Meeting on Advanced Rotorcraft Technology and Life Saving Activities, Tochigi, Japan, Nov. 2002.
5) Funabiki, K., Kobayashi, K. Miyata, T., "Simulation Study on Trajectory-based High Density Operations with Helicopters," Proceedings of 24th Digital Avionics Systems Conference, Oct. 2005.