FLIGHT DEMONSTRATION OF A NEW OPERATIONAL CONCEPT USING TDMA DATA LINK SYSTEM

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Abstract

The Japan Aerospace eXploration Agency (JAXA) and the Electric Navigation Research Institute (ENRI) have been working on a research project called "NOCTARN (new Operational Concept using 3D Adaptable Route Navigation)" which aims at demonstrating a new CNS/ATM(communications navigation, surveillance / aircraft traffic management) concept to reduce the noise impact of aircraft to communities around airports while enhancing flight safety. In this concept, approach and take-off trajectories are shared between the aerodrome controller and aircraft using radio data link communication.

As the initial stage of flight demonstration of this concept, two series of flight tests have been conducted using JAXA's research airplane and helicopter. The objectives of the flight tests are to evaluate the capability of an experimental TDMA (Time Division Multiple Access) data link system and to demonstrate proposed air-ground communication procedures. The paper outlines the NOCTARN concept and describes flight test results.

1. Introduction

In spite of the increasing demand for air transportation, airports cannot easily expand to accommodate such demands. Many airports are located near noise sensitive areas and so raising the number of aircraft movements is often difficult. However, using three dimensional flexible approach patterns instead of conventional straight approaches could enable airports to handle more traffic while limiting noise impact [1] on local communities.

JAXA and ENRI have been developing the NOCTARN concept [2] which enables aircraft to use such flexible three dimensional approach patterns. The basic concept of NOCTARN is shown in Fig. 1.

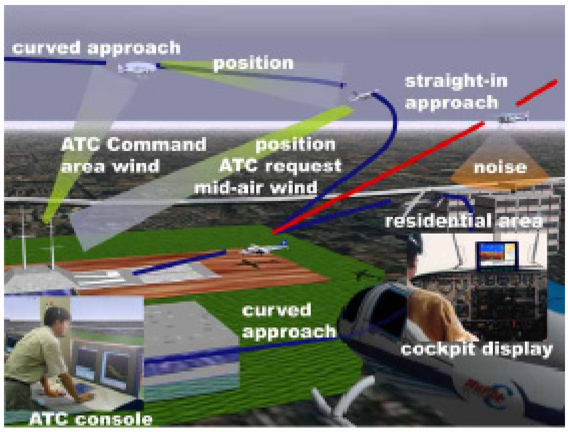

Fig. 1 Basic concept of NOCTARN

In this concept, a NOCTARN control zone is established around the airport (Fig. 2). Once aircraft with NOCTARN equipage enter the control zone through a gate, they can negotiate with the aerodrome controller by wireless data link using Controller Pilot Data Link Communication (CPDLC) instead of conventional voice communication. At the same time, the controller receives information on the NOCTARN aircraft via the data link and then gives directions such as assigning an approach pattern. Data link messages exchanged between the pilot and controller are displayed both on a cockpit MFD (Multi Functional Display) in the aircraft and on the controller's console. Each NOCTARN aircraft automatically receives information transmitted by other NOCTARN-equipped aircraft on the same data link in a manner similar to Automatic Dependent Surveillance-Broadcast (ADS-B), and this information is also displayed on the MFD as a Cockpit Display of Traffic Information (CDTI), as well as on the controller's display.

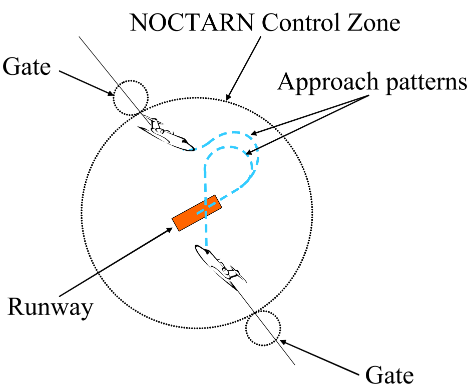

Fig. 2 NOCTARN control zone

In the next section, we describe the systems necessary for NOCTARN operations.

2. NOCTARN experimental configuration

The NOCTARN system comprises an airborne subsystem and a ground subsystem, both equipped with a digital data link communication system. In this section, we describe each subsystem developed for the NOCTARN flight tests.

2.1. Data link communication system

For the flight test, we have developed a data link communication system using a UHF TDMA data link transceiver (Fig. 3) with a 5W transmitter. The transceiver measures 238mm(w) x 250mm(d) x 91mm(h) the weighs 5kg. The clock signal for TDMA timing is derived from the L1 band (1575.42MHz) GPS signal. When the system can receive signals from four GPS satellites, the precision of clock signal is +/−1μs.

The TDMA system has 13 time slots per frame, each with 72 bytes of free data available to store arbitrary information. All slots are updated at one second intervals (1Hz frame rate). At present, each slot is assigned manually either to a single aircraft or to the aerodrome controller.

A downlink data packet (transmitted in slots assigned to aircraft) is composed of a fixed-size header and a variable-sized data area of up to 52 bytes. The variable sized area contains two types of data listed below

- Aircraft status
  - horizontal position, altitude
  - heading
  - airspeed, ground speed, vertical speed
  - estimated wind
- CPDLC downlink messages

While the aircraft status information is transmitted continually at one-second intervals, CPDLC downlink messages are sent only when initiated by the pilot.

Fig. 3 TDMA data link transceiver

An uplink data packet (transmitted in the slot assigned to the aerodrome controller) also comprises a fixed size header and variable size data area of up to 64 bytes, which contains two types of data listed below

- CPDLC uplink message
- Area Wind information

CPDLC uplink messages are transmitted only when the controller selects a message on the console. Area wind information contains ground wind derived from a wind sensor at the aerodrome and estimated wind information derived from the periodic aircraft downlink estimated wind reports.

2.2. Airborne subsystem

The NOCTARN airborne subsystem consists of a data link communication unit, a flight guidance and display computer, and a cockpit MFD as shown in Fig. 4. The data link communication unit is connected to the flight guidance computer by a serial communication bus. The flight guidance computer collects data from air data sensors and a GPS navigation system which it then transmits as downlink information.

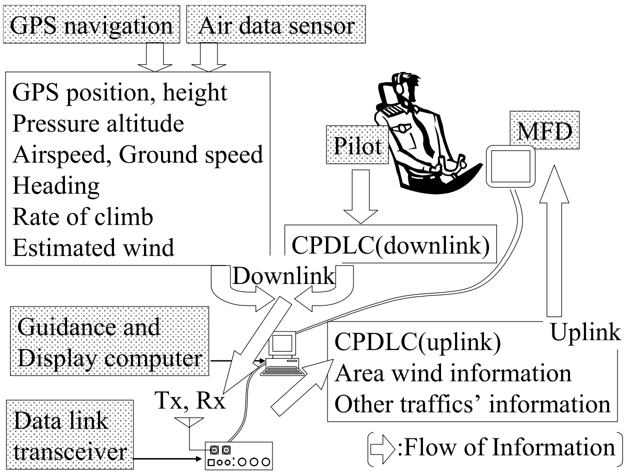

Fig. 4 Airborne subsystem configuration

When CPDLC uplink (controller to pilot) messages and area wind information are transmitted to the aircraft in uplink messages, the information is displayed on the MFD. When a CPDLC message is received from the controller, such as the assigned approach pattern or a landing clearance, it is displayed on the MFD as a blinking text message, and also annunciated by a synthetic voice generated by the flight guidance computer. Appropriate pilot responses (e.g. WILCO) are also displayed on the MFD, which the pilot can then select to respond to the controller's message. A synthetic voice is also generated when the pilot transmits the response.

Area wind information is displayed on the MFD, and is also used to modify the assigned approach pattern to compensate the wind to enable smooth tracking of the pattern by the pilot. The modified approach pattern generated by the flight guidance computer is displayed on the MFD as tunnel-in-the-sky [1]. By following the guidance of this tunnel, the pilot can track the three-dimensional approach pattern easily.

Information on other NOCTARN traffic in the NOCTARN control zone is also displayed on the MFD. The pilot can check other aircrafts' call sign, relative position, speed, height, heading, and assigned approach pattern.

In the flight tests, we have used JAXA's research airplane "MuPAL-α"(JA8858)[3] based on Dornier 228 (Fig. 5) and helicopter "MuPAL-ε"(JA21ME) [4] based on Mitsubishi MH2000 (Fig. 6). Both aircraft are equipped with the NOCTARN airborne subsystem. Fig. 5 and Fig. 6 also show the antennas for data link communication.

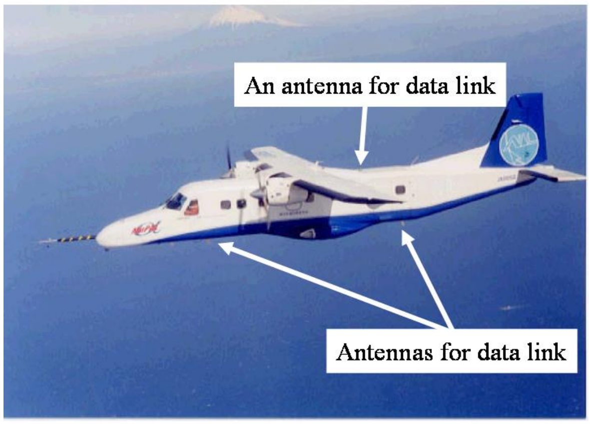

Fig. 5 MuPAL-α (JA8858)

Fig. 6 MuPAL-ε (JA21ME)

2.3. Ground subsystem

The NOCTARN ground subsystem consists of a data link communication unit, a data link station, a wind measurement station, an ATC (air traffic control) server station, and an ATC console as shown in Fig. 7. The data link communication unit is connected to the data link station by a serial communication link.

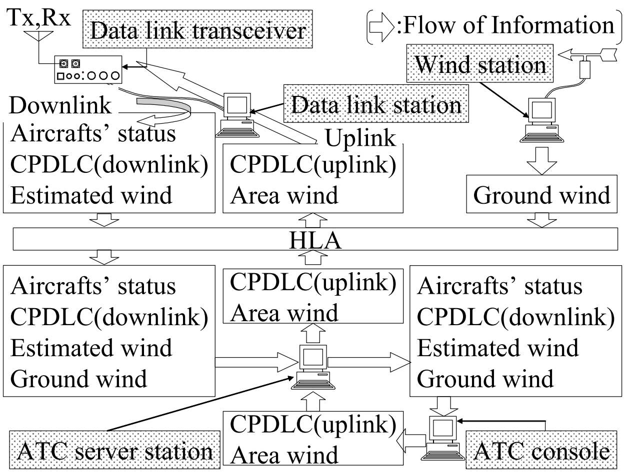

Fig. 7 Ground subsystem configuration

Downlink messages contain NOCTARN aircraft status, CPDLC downlink message (pilot to controller), and estimated wind information. After receiving the information, the data link station makes it available for sharing among the ground subsystem elements using the HLA (High Level Architecture [5]) distributed data object system [6]. The data link station, ATC server station and wind station in Fig. 7 are able to access and create data objects as HLA federates.

The ATC server station receives aircraft status information, CPDLC downlink messages, estimated wind information and ground wind information from the HLA, and sends it to the ATC console for display to the controller. The controller can view aircraft status on the ATC console display (Fig. 8) and also compose CPDLC uplink messages to issue instructions. Similar to a conventional ATC radar display, aircraft call sign, height, heading and airspeed are displayed continually in a text data block next to the aircraft's position symbol. The ATC console display also allows the controller to review the CPDLC messages previously exchanged with each aircraft.

When a CPDLC downlink message is received from an aircraft, the controller reads the message from the console display and then selects an appropriate response uplink message, such as an approach pattern or landing clearance. If necessary, the controller can also compose messages that command a particular height, speed or heading. Uplink messages are sent from the ATC console to the HLA via the ATC server, then transmitted to the aircraft.

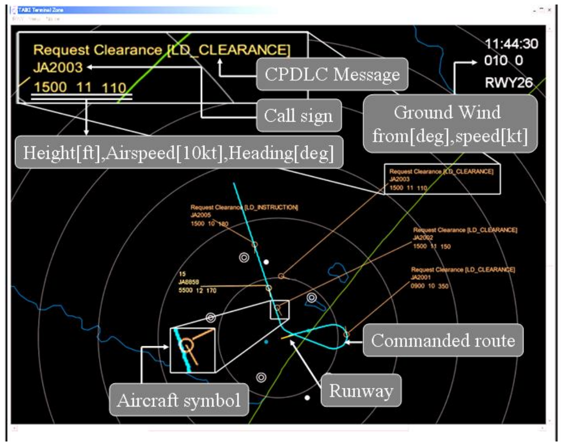

Fig. 8 ATC console display

Ground wind information from the wind station is also displayed on the ATC console. The ATC console stores the ground and estimated wind information, and from it generates the area wind information which is sent to aircraft. This area wind information is updated every 6 seconds.

3. Flight tests

We have carried out two types of flight test of datalink communications. The first test was conducted at Taiki Multi-Purpose Aerospace Park, Taikicho, Hokkaido, using a single aircraft and a ground subsystem to check air to ground communication. The second test was conducted at the kanto area experimental field, using multiple aircraft and a ground subsystem to check air to air communication.

3.1. Air to ground communication

This experiment was conducted at Taiki Multi-Purpose Aerospace Park, which has a 1000m runway (08/26). The ground subsystem data link antenna (Fig. 9) was sited about 1m above the ground 500m from the runway centerline, almost abeam the departure end of runway of 08.

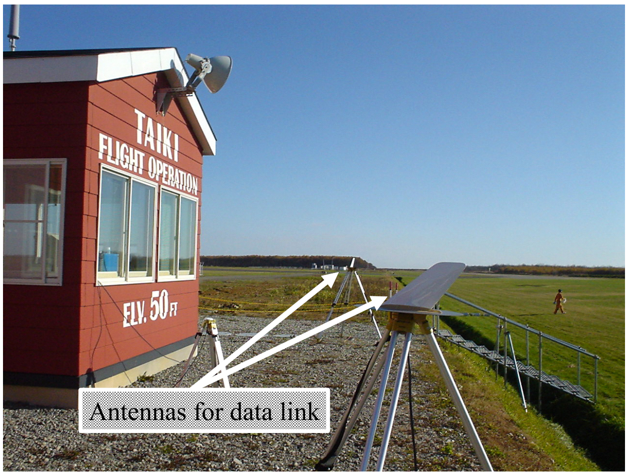

Fig. 9 Antennas for TDMA datalink communication

To check basic connectivity between the aircraft and the ground, we used an orbital route and straight route around the airport. First, the aircraft flew in a circle around the antenna, then from east to west along the runway extended centerline, and finally from south to north across the runway perpendicular to the axis. The status of the data link connection was monitored during the flight, and the result is shown in Fig. 10 and Fig. 11.

Fig. 10 shows the result of the flight test with JA21ME. The radius of the circular orbit was about 5km and was flown 300m above ground level (AGL), and the length of the straight route was about 25km and was flown at 600m AGL. The blue line indicates the ground track of JA21ME and the black stars indicates the points at which the data link connection was lost.

Fig. 11 shows the result of the flight test with JA8858. The radius of the circular route was about 10km and the length of the straight route was about 35km. In this case, the whole route was flown at 300m AGL. The green line indicates the ground track of JA8858.

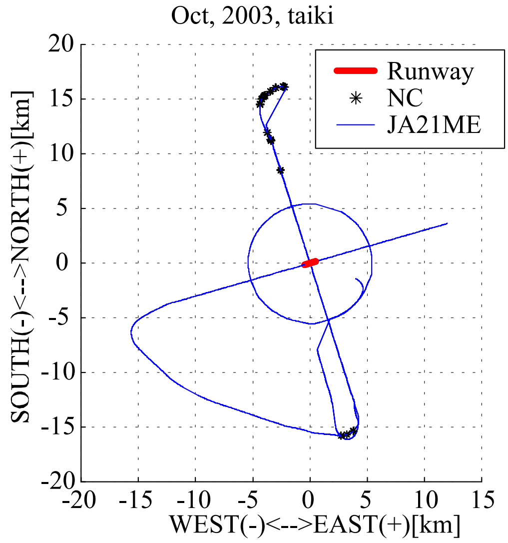

Fig. 10 Coverage check at Taiki Multi-Purpose Aerospace Park with JA21ME

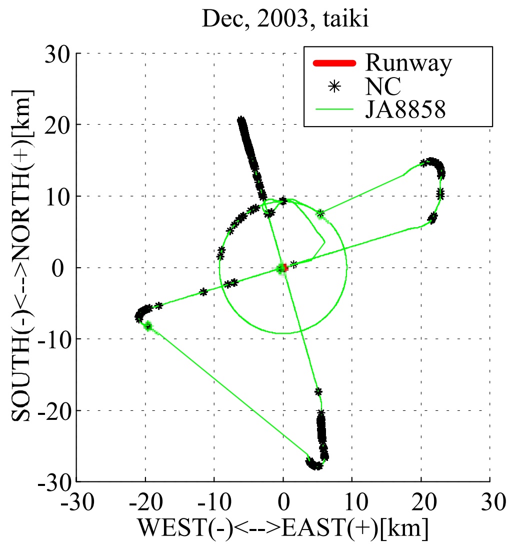

Fig. 11 Coverage check at Taiki Multi-Purpose Aerospace Park with JA8858

3.2. Air to air and air to ground

This test was conducted at kanto area, 70km north west of Chofu airport in Tokyo where JAXA's research aircraft are based. The aircraft flew from Chofu to the experimental field. In this test, a "virtual" runway was established in the air 1200m above the field, and was used for the aircraft to carry out repeated approaches and landings. The ground subsystem antenna was located at Chofu airport 500m east of the runway centerline and about 15m above the ground. We first re-checked the connectivity between the aircraft in the experimental field and the ground subsystem antenna. Then we performed basic tests and approaching tests for air to air communication.

3.2.1. Air to ground communication test

In this test, we re-checked the capability of air to ground communication for the kanto area experimental field and Chofu airport. The result is shown in Fig. 12.

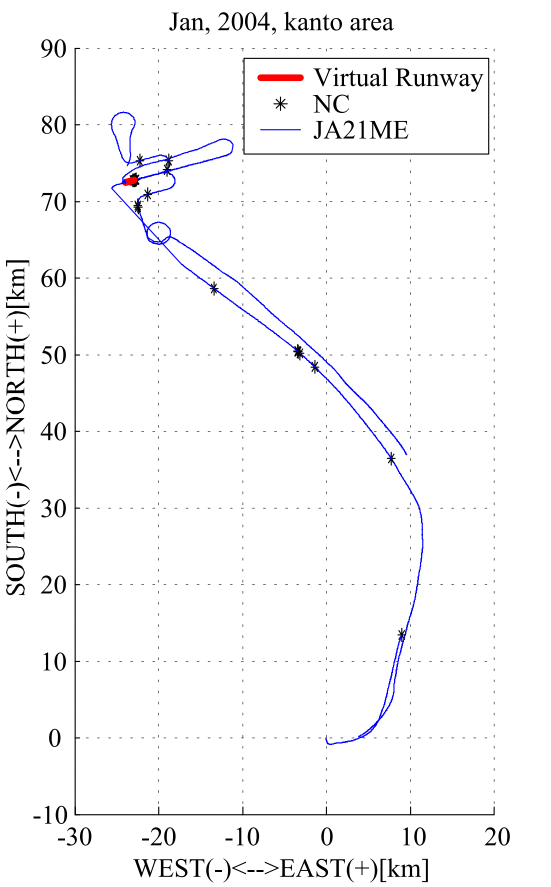

Fig. 12 Coverage check at kanto area with JA21ME

In this figure, the origin is placed at the center of the runway of Chofu airport. The virtual runway is shown as the red, the blue line shows the ground track of JA21ME, and the black stars indicate the points at which the air-ground data link became disconnected. In this case, JA21ME flew from Chofu airport to the experimental field. Then tried to approach and landing to the virtual runway for several times

3.2.2. Basic tests for air to air communication

These tests were conducted while the two aircraft were flying to the experimental field. First test was to check connectivity while one aircraft catching up with another aircraft in several vertical displacement. Second test was to check connectivity while one aircraft fly above/below the another aircraft.

For the first test, JA21ME flew ahead of JA8858 at 105kt, the same flight level. JA8858 flew at 155kt to catch up with JA21ME. After JA8858 caught up with JA21ME, JA8858 climbed up 300m and tried to catch up with JA21ME again. Finally, JA8858 descended 600m and do the same thing. For the safety, 2km horizontal displacement was assured between two aircraft. The result of this test is shown in Fig. 13. In the figure, aircraft fly from right side which marked as diamond then to left side.

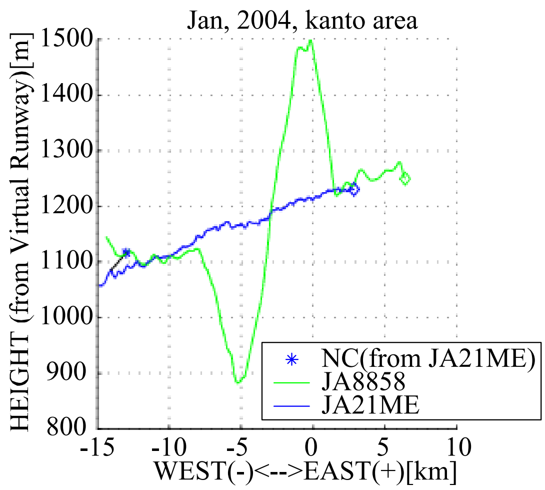

Fig. 13 Connectivity check for air to air communication (catching up)

For the second test, two aircraft flew parallel each other with 2km horizontal displacement. Then JA8858 flew above JA21ME while keeping their vertical displacement, about 300m. In this test, JA21ME flew at 110kt and JA8858 flew at 155kt.

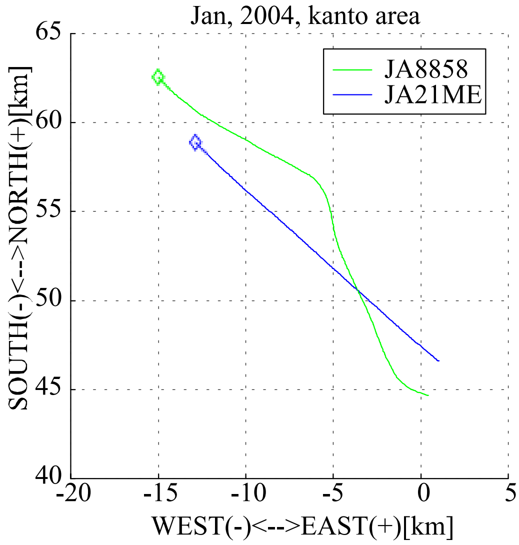

Fig. 14 Connectivity check between air to air communication (crossing)

In those figures, the position of the origin is the same as in Fig. 12. The green line indicates the ground track of JA8858 and the blue line that of JA21ME. The blue stars indicate points where JA8858 could not communicate with JA21ME, and the green stars vice versa. The black line indicates the position of the other aircraft when the disconnection occurred. Diamonds in the figures indicate the starting position of each aircraft.

3.2.3. An approaching test for air to air communication

Finally, we checked connectivity between aircraft while approaching to the virtual runway. A typical result is shown in Fig. 15. In this figure, two aircraft were trying to approach to the virtual runway simultaneously. In this case, we prepared three types of approach patterns for the pilot which is displayed on the MFD. The pilots can monitor another aircraft each other then select appropriate approach pattern not to harm their safety. JA8858 flew from east side of the runway to take straight approach pattern. Then about 1 minute later, JA21ME flew from south side of the runway to take curved approach pattern. They were approaching from about 500m above the virtual runway at 105kt. In Fig. 15, the markers, lines, position of origin, and position of virtual runway is the same as Fig. 12.

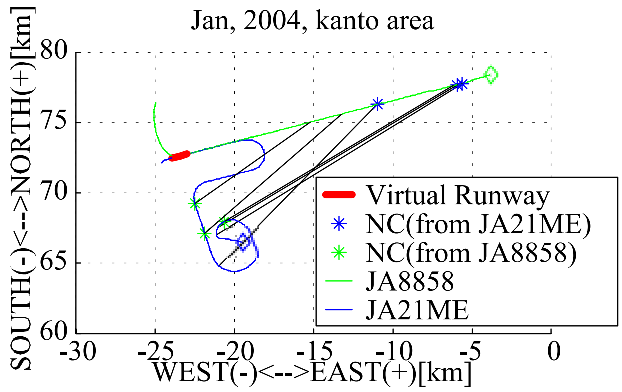

Fig. 15 Connectivity check for air to air communication (approaching)

4. Discussion

As shown in Fig. 10 and Fig. 11, in the air-ground connectivity test at Taiki Multi-Purpose Aerospace Park, the data link connection becomes unreliable at about 15km from the antenna. However, the transmitted power (5W) should be sufficient for data link communications, as shown in Fig. 12. In this figure, there are fewer disconnections than in the experiment at Taiki, even though the aircraft is operating further (70km) from the antenna.

The disconnections during tests at Taiki were the result of the position of the ground subsystem antenna (only 1m above the ground) and a 30m tall building about 100m north of the antenna. Therefore it was difficult to communicate when the aircraft was north of the antenna with the building blocking the line of sight. On the other hand, the ground subsystem antenna at Chofu was placed 15m above the ground and were no obstacles in the line of sight to the aircraft.

However, in Fig. 11, disconnections occurred not when the aircraft was north of the antenna, but also when it was on the south side. In this case, the test was conducted using the Dornier 228 aircraft. This aircraft has the data link transmission antenna installed on the bottom of the fuselage, while the data receiver antenna is on the top. When the aircraft banks, the fuselage can mask the signal from the ground to the aircraft antennas.

From post-flight interview comments, pilots often had doubts about the connectivity between the aircraft and the controller. Unlike ATN (Aeronautical Telecommunication Network) CPDLC, the "ACK" signal is not built into the protocol yet. Therefore the pilots often doubted that the messages had been transmitted correctly. Although if the connection have been established, the latency appears to be too long for pilots in a terminal environment, especially when they waiting some response from the controller. The TDMA data link frame rate is 1Hz and so at least four seconds are required for the pilot to get a response from ATC to a message, and in reality a few more seconds are necessary for the human performance of the controller in identifying, processing and responding to the request appropriately. There were also cases of genuine non-delivery of messages due to software bugs and problems with the radio data link.

Further, a synthetic voice message is generated for the pilot when sending and receiving CPDLC messages. Pilots feel that the message has been sent from the aircraft when the voice message has finished, but in fact a downlink message is transmitted before the voice message is annunciated. Therefore, generating the voice message has the psychological effect of shortening the apparent response time.

In some cases, the synthetic voice overlapped other voices such as of other crewmembers on the aircraft intercom or VHF voice transmissions. In such cases, pilots also felt that the messages had not been sent correctly.

In Fig. 13 through Fig. 15, only a few disconnection points have appeared. In those cases, the antennas are masked by the body however it does not seem to be a big problem for the connectivity between aircraft. However, these cases were held in relatively good condition for data link communication. Therefore further experiment is required.

5. Conclusions

This paper has described an experimental system for the NOCTARN concept, and demonstrated the coverage and capability of the system's data link in two flight experiments.

The first experiment showed the basic data link coverage area around an airport, while the second experiment verified air to ground and air to air connectivity. From those results, the experimental system has sufficient capability for further experiments with NOCTARN operations. However, it is necessary for the software to be more reliable.

In the future, multi-aircraft experiments will be conducted including the use of simulated aircraft amongst real traffic. The HLA system enables us to add dummy aircraft easily to both a "live" system and a pure simulation. Furthermore, we will have an evaluation for ATC console by air traffic controllers.

6. References

[1] Funabiki, K., Muraoka, K., Terui, Y., Harigae, M. and Ono, T., *In-flight Evaluation of Tunnel-in-the-Sky Display and Curved Approach Pattern*, AIAA Guidance, Navigation and Control Conference and Exhibit, pp.108-114, 1999.

[2] Funabiki, K., Muraoka, K., Iijima, T. and Shiomi, K., *NOCTARN: Trajectory Based CNS/ATM Concept for Small Aircraft,* Proceedings of 21st Digital Avionics Systems Conference, 2002.

[3] Masui, K. and Tsukano, Y., *Development of a New In-Flight Simulator MuPAL-α*, AIAA-2000-4574, AIAA Modeling and Simulation Technologies Conf. and Exhibit, 14-17 Aug. 2000.

[4] Y. Okuno, N. Matayoshi and H.Ishii, *Recent Research Programs of the MuPAL-ε Research Helicopter,* Proceedings of International Council of the Aeronautical Sciences, 2004(to be printed).

[5] Defense Modeling and Simulation Office (DMSO); RTI 1.3-Next Generation Programmer's Guide Ver. 3.2, 2000.

[6] Muraoka, K. and Funabiki, K., *Distributed Simulation for NOCTARN*, AIAA Modeling and Proceedings of Simulation Technologies Conference and Exhibit., 2001