Air Traffic Controllers' Workload on the Period of ATC Paradigm Shift

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Abstract: The real time simulation was performed in order to investigate the influence of the introduction of CPDLC into Japanese domestic ATC operations. The simulation was carried out with the participation of retired ATC controllers. Based on the results, it was considered that the introduction of CPDLC would be effective to reduce total communication time for ATC instructions, but it was also confirmed that the ATC workload is not simply dependent on the length of communication time. It is impossible to avoid the increase of workload in the transient situation, and it is not desirable from the viewpoint of the operational workload of ATC controllers that the introductory situation of 30% of aircraft with CPDLC capability continues for a long term.

Keywords: ATC, CPDLC, workload

1. INTRODUCTION

It is expected that the introduction of CPDLC (Controller-Pilot Data Link Communication) into the Air Traffic Control (ATC) operations will improve ATC safety and reliability by eliminating incorrect hearing in the present analogue voice communication, etc., since the quality of current analogue VHF radio communication is not sufficient.

In Japan, CPDLC has been introduced into the ATC operations of the Pacific Oceanic area, since the ATC instruction interval is relatively large in the oceanic ATC area, and ATC controllers have sufficient time to carry out CPDLC operations. In the U.S. and Europe, CPDLC of the domestic air route ATC operations have already been introduced now, but the introduction is not yet in Japan.

It is clear that the transition to data communication from analogue voice communication greatly shortens spatial occupancy time of radio waves in ATC air-ground communication. Therefore the introduction of CPDLC significantly improves the use efficiency of radio wave resources. It is also considered that a wider introduction of CPDLC into Japanese domestic ATC operations is necessary to improve the efficiency of utilization of radio wave resources, and to keep sufficient radio wave resources required in the near future.

The Japanese Civil Aviation Bureau (JCAB) is now seeking to carry out their introduction plan of CPDLC as an important part of overall future planning, named CARATS (Collaborative Actions for Renovation of Air Traffic Systems). The JCAB is expecting the improvement of the convenience of ATC operations, the efficiency of air transportation, and the total air safety with the introduction of CPDLC.

2. THE FIRST STEP FOR CPDLC INTRODUCTION

The wider introduction of CPDLC into Japanese domestic air route ATC operations will be inevitable in the near future.

And now, there are two ways to introduce CPDLC in Japan; one way is to introduce a CPDLC system similar to that introduced in the U.S. and Europe domestic air route ATC operations, and the other way is to develop the Japanese CPDLC system corresponding to the requests from Japanese ATC controllers.

But no one knows which way is better for the first step of the introduction of the Japanese domestic air route ATC operations, since Japanese is currently in a unique situation. Japanese airspace is not as overcrowded as Europe, and VHF radio wave resources are also not in short supply at present.

When the Japanese CPDLC is introduced into the Japanese domestic air route ATC operations, it has to have minimum compatibility with the CPDLC of the U.S. and Europe, since the Japanese CPDLC must be valid for international flights from the U.S. and Europe in Japanese airspace.

However, the most important thing in the first step of the introduction of CPDLC into the Japanese domestic air route ATC operations is to minimize ATC controllers' contradictory feelings towards the introduction of CPDLC by minimizing the impact of its introduction on the current ATC operation environment.

In the current Japanese situation that there is no severely congested airspace except in the Kanto-South sector (Southern side of the Tokyo Metropolitan area) in which many aircraft are cruising to Tokyo/Haneda International Airport, and there are few pressing problems in the current ATC operation environments. Due to this situation, the introduction of CPDLC will not be expected to be greatly welcomed. It is then very important that the introduction of the CPDLC will never annoy or trouble the ATC controllers.

The study on the CPDLC is aiming to make clear the way to introduce CPDLC into the Japanese domestic ATC operation as the first step of the next CPDLC paradigm, and also aiming to establish a firm foothold for the second step by giving answers to the following questions.
In the first step of the introduction of CPDLC,
a) What kinds of CPDLC messages will have to be handled?
b) How much will it reduce the time for ATC communication?
c) How will ATC controllers' workloads change?
We were required to answer as quantitatively as possible the above questions.

If the basic data such as contents of domestic air-ground ATC communication, their frequency, etc. exist, it is possible to estimate the expected length of the communication time that will be reduced by the introduction of CPDLC. It will be possible to calculate the relationship between the expected reduced ATC communication time and the contents of introduced CPDLC messages. Since the performance of VHF radio communication media used for CPDLC is given as statistical data, the relationship between the reduced time and the CPDLC messages is able to be calculated more precisely by making use of fast-time simulators, etc.

However, it is impossible to obtain any information about behavior change of an ATC controller, who has "humanity" associated with changes in operation configuration, occurrence of new-type human errors, the sense of the ATC workloads, etc. from the approximate calculation or the fast-time simulation, because it assumes a simplified CPDLC model that eliminates the human factors.

Since the subjective evaluation of the first step of the introduction of CPDLC into the ATC operations has to be made by ATC controllers as the users of the CPDLC system after the introduction, the provider of the system must prepare to make the CPDLC system acceptable by them, and to get higher evaluation scores. Since the good usability of handling CPDLC messages strongly depends on the design of the user interface, it is essentially necessary for the system provider to repeat the evaluation and improvement of the user interface for ATC controllers, such as GUI, custom input devices, etc.

The aim of this study on the introduction of CPDLC into the Japanese domestic ATC operations was to obtain useful data for preparation of the introduction as the results of the real-time ATC simulations that were carried out with the cooperation of ATC controllers. As it was possible to perform proper CPDLC/ATC simulations without being affected by unnecessary dissatisfaction such as due to poor operational capabilities when handling CPDLC messages, we had prepared the CPDLC/ATC

simulator which looks sophisticated enough, and which had enough capability for handling the messages.

Our study aimed to obtain quantitative answers to the questions mentioned above, and also aimed to obtain some additional information for thinking about the second step of the introduction of CPDLC and the following steps.

3. CPDLC/ATC SIMULATION

The long-term aim of the introduction of CPDLC into world global ATC is to correspond to the needs in the future paradigm of the fourth dimensional trajectory management of aircraft. In the future paradigm of 4D-trajectory management, it will be necessary for the ATC controller to give very complex instructions, which is difficult to communicate by the current analogue voice, and then he or she has to use CPDLC to give instructions. A set of CPDLC messages is already designed to be able to handle the complex, high-level, and advanced ATC instructions.

With the exception of exceptional circumstances, the ATC controller will no longer command flight altitude, flight direction and flight speed to individual aircraft in the future paradigm of 4D-trajectory management. However, in the introductory period of CPDLC, it can be thought that there will be many situations where the ATC controller has to make CPDLC messages to command flight altitude, flight direction and flight speed to individual aircraft.

**Figure 1: Custom Input Device for CPDLC Messages**
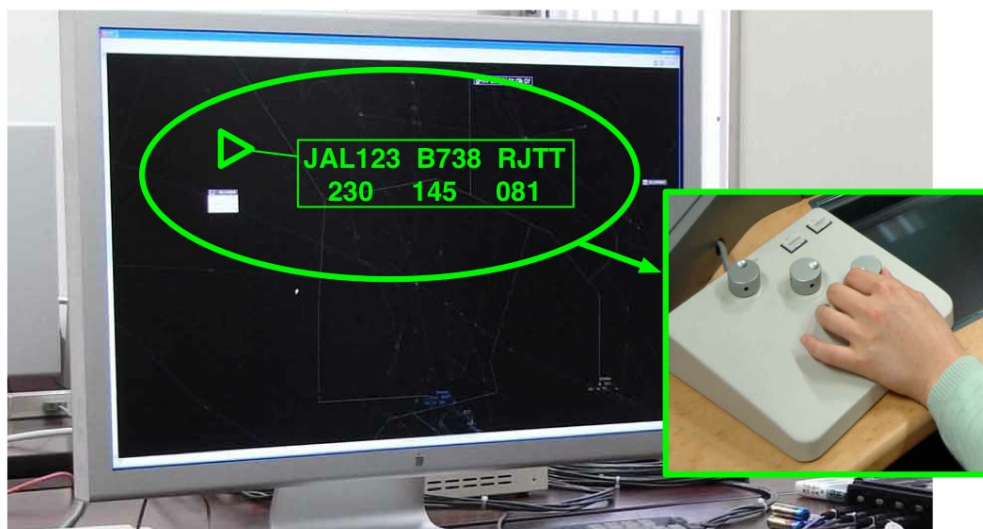
The data input device shown in Figure 1 was one of the custom input devices designed and developed for quick change of aircraft's flight altitude, flight direction and flight speed in CPDLC messages. However, these special input devices were not used in the CPDLC/ATC simulation, since the ATC controllers who participated in the simulation used a regular wheel-mouse for handling CPDLC messages. Fortunately or unfortunately for us, the combination of the wheel-mouse and the pop-up menu was enough for the ATC controllers' message handling in the simulation.

3.1. CPDLC/ATC Simulator

Figure 2 shows the CPDLC/ATC simulator prepared for simulation of the introduction of CPDLC into Japanese domestic ATC operations. The simulator has two large LCDs and one small LCD. One of the large LCDs displays the information for the participant who plays the role of an ATC controller in the simulation. The other large LCD displays the information for the participant who plays the role of an aircraft pilot. The small LCD displays the GUI to control the simulation for the simulation supervisor.

Figure 2: Appearance of the CPDLC/ATC Simulator

Display for the participant who plays the role of an aircraft pilot

Display for the participant who plays the role of an ATC controller

Display for the simulation supervisor
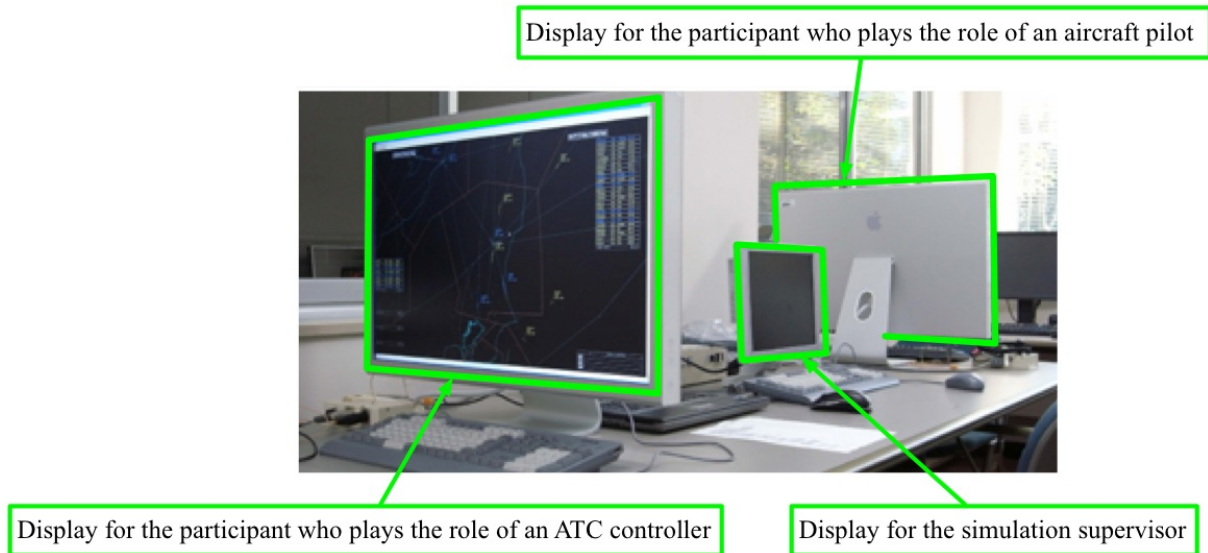
The displayed information on the large LCD is designed according to the current digitalized ATC radar image display. The LCD displays the positions of aircraft on an airspace sector map, which consists of air routes, waypoints, etc. Figure 3 shows the displayed image provided by the simulator for ATC operations and a real radar image provided for the ATC controller by the current actual ATC information system. Though the position of an aircraft is indicated with a triangle symbol in the current actual ATC system, the position of an aircraft which has CPDLC capability is indicated with a circle symbol, as shown in Figure 4, in the simulator to discriminate between conventional aircraft without CPDLC capability and new aircraft with the capability.

Figure 3: Displayed Images for the ATC Controller
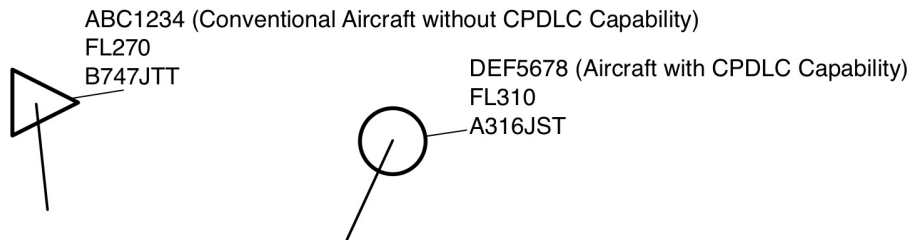

The left image is a simulated display image, and the right image is a picture of an actual radar display.
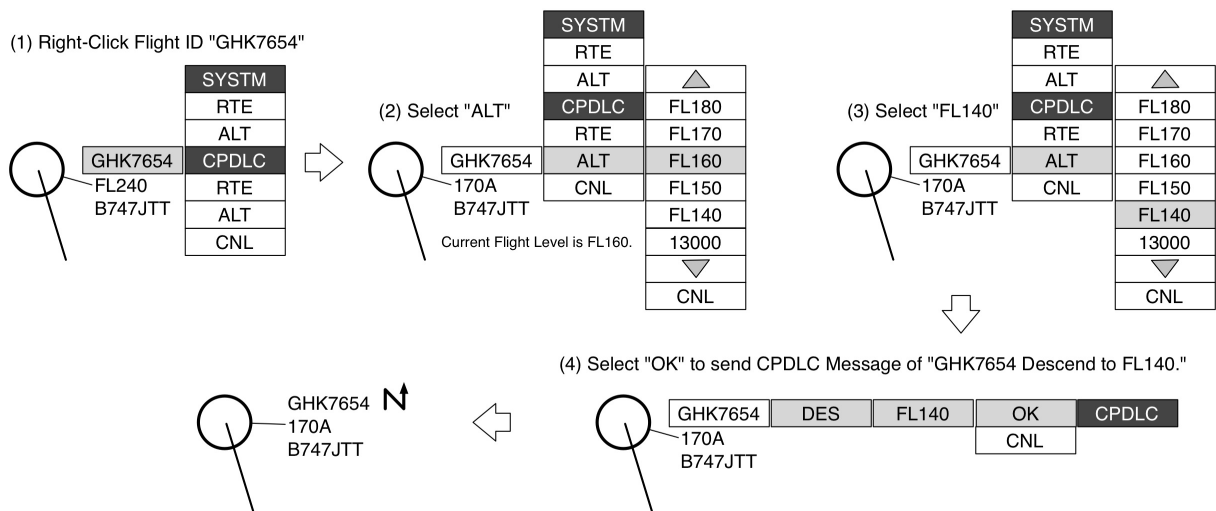
Both large LCDs display almost the same information and look almost the same, since the participant who plays the role of an aircraft pilot has to control the same number of aircraft that were instructed by the ATC controller.

The ATC controller can create a typical CPDLC message by selecting the pop-up menu according to the procedure shown in Figure 5. After creating the CPDLC message as shown in Figure 5 (4), if the "OK" button is clicked, the CPDLC message is sent to the target aircraft, and a symbolized up-link icon is displayed until the acknowledgment signal from the aircraft is received.

Figure 4: Aircraft's Symbols displayed in the ATC Information Display

ABC1234 (Conventional Aircraft without CPDLC Capability)
FL270
B747JTT

DEF5678 (Aircraft with CPDLC Capability)
FL310
A316JST

Figure 5: Procedure to create CPDLC Message

**Figure 6: Pop-Up Menu for Creating CPDLC Messages**

Figure 6 shows the situation when the ATC controller creates a CPDLC message to change the flight direction. In the case shown in Figure 6, item "190" is highlighted in the pop-up menu, since the current flight direction of the selected aircraft is 190 degrees.

3.2. CPDLC Simulation Scenarios and Conditions

Figure 7 shows a picture of the CPDLC/ATC simulation being carried out. Since the participant playing the pilot role should frequently coordinate with the ATC controller and the ATC coordinator, they carried out the simulation sitting next to each other. Since this seating resembles the actual ATC environment as shown in Figure 8, it is considered that this would not likely become a factor in increasing the workload of the participant playing the role of ATC controller.
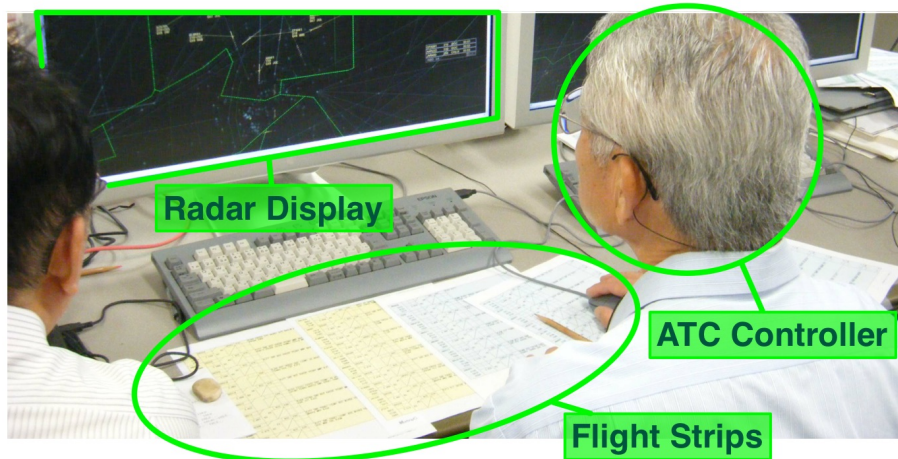
Figure 7: Configuration of the CPDLC/ATC Simulation
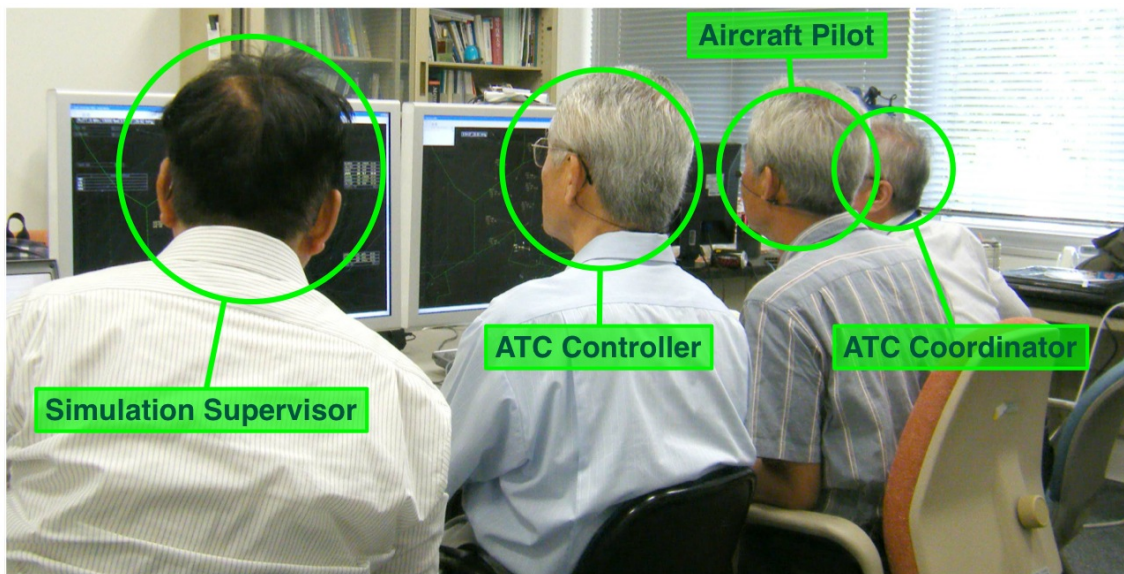
Figure 8: Configuration of Actual Japanese ATC Environment in 2008
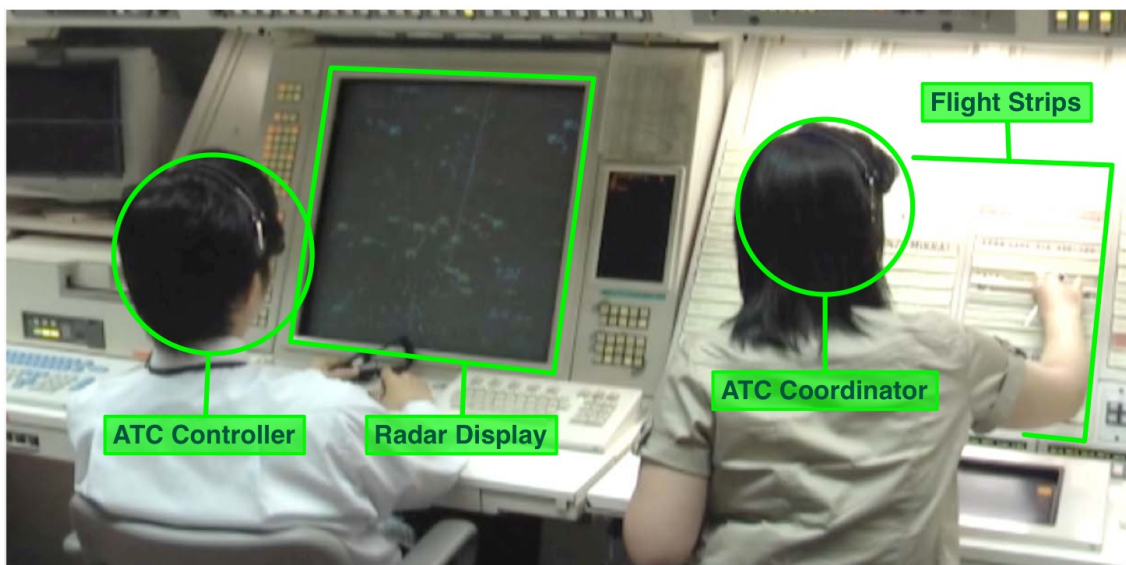
Figure 9: Layout of Radar Display and Flight Strips

Flight strips representing flight information of aircraft were preliminarily printed according to the current Japanese ATC format, and arranged in front of the Radar display as shown in Figure 9.

The Kanto-North (Northern side of Tokyo) sector was set as the airspace for CPDLC/ATC simulation. Though the Kanto-North sector is not as congested as Kanto-South, it has a rich variation of flights. The Kanto-North sector adjoins the Japanese major terminal airspace of two major airports, Haneda/Tokyo and Narita/Tokyo. And the ATC controllers deal with passing flights from the Pacific Ocean, take-off and landing flights of small aircraft at Fukushima airport, and military aircraft at Hyakuri/Ibaraki, Yokota/U.S. Air-Force, etc.

The Kanto-North sector has various air routes at an altitude of between 9,000 feet and 37,000 feet. This structure of airspace makes it possible to carry out complex ATC operations including changing flight altitude. And it is suitable for the simulation with the expectation of some or more additional results, which cannot be obtained without good luck.

One of the important things that must be revealed by this simulation is to confirm the validity of the contents of the set of CPDLC messages that will be introduced into the Japanese domestic ATC operation at the introductory phase. The contents of the set of CPDLC messages must correspond to the characteristics of the CPDLC communication media and ATC operational environment.

At first, in this simulation, it was assumed that it would be best to use VDL (VHF Digital Link) Mode-2 as air-ground communication media, since the JCAB had already decided to use VDL Mode-2 as the data link media for CPDLC in Japanese domestic airspace. VDL Mode-2 will be useful enough to send complex messages, such as Pre-Departure Clearance, the CPDLC message for setting 4D-trajectory of aircraft, etc. in the future paradigm of 4D-trajectory management, since ATC instructions consist of complex contents which do not require a quick response from an aircraft pilot. However, VDL Mode-2 will never provide the real-time feature like analogue voice communication. In the data link communication on VDL Mode-2, every message will be delayed by about three seconds, as averaged delay time, and some messages will be delayed by more than 10 seconds. It is impossible to carry out real-time communication like daily conversation by using VDL Mode-2. Also, in the data link communication on VDL Mode-2, a message sent later may arrive earlier than another message sent before it.

The experiments for the evaluation of the VDL Mode-2 function and performance were carried out, and consequently the function for simulating the VDL Mode-2 performance was implemented in the CPDLC/ATC simulator used in this simulation.

The functions of the CPDLC application were implemented according to the ATN (Aeronautical Telecommunication Network) regulations that were approved by the ICAO (International Civil Aviation Organization) [1].

Since the CPDLC application has the function to confirm message delivery, the application repeats sending a message until an automatic acknowledgement is received from the objective destination aircraft, even if the lower communication protocol does not have the acknowledgment function. The logical delivery confirmation function implemented in the CPDLC application is considered essential to ensure reliability of interactive communication on the VDL Mode-2 with poor data-link capability.

The data link characteristics of VDL Mode-2, the CPDLC application function mentioned above, the corresponding functional level on the side of the aircraft, the current Japanese ATC operation environment, etc. interfere with the use of some kinds of CPDLC messages. A utilizable set of CPDLC messages will be limited according to both the aircraft cruising functions and the total environments of ATC operations.

Though a limitation in the set of CPDLC messages existed in the CPDLC evaluation tests carried out in Europe and the U.S., the limitation itself had not always been considered a severe problem. However, it is also true that a limitation in the message set would seem unnatural to the ATC controllers, if CPDLC messages were simply regarded as an alternative to voice instructions.

In this simulation experiment, the following message services were set to be able to be used for ATC operations: frequency change instruction messages as the ACM (ATC Communications Management) service message, and both flight altitude change instruction messages and flight direction change instruction message as the ACL (ATC Clearances) service messages.

But flight speed change instruction messages were not available, because the ATC controller had no way to know the current flight airspeed. In order to accurately instruct flight speed change it is necessary for the ATC controller to know current flight airspeed affected by wind before giving the instruction. There is no other way to know the current flight airspeed of aircraft than by the ATC controller questioning the pilots, and it is suggested not to do so from the point of view of operational workload increase due to interactive message exchange, under the situation of larger transmission delays occurring on the VDL Mode-2 data link. Therefore the flight speed change instruction does not allow the ATC controllers to use it as long as the current airspeed data is not distributed automatically from aircraft through DAPs (Downlink Aircraft Parameters), etc.

It is also considered that utilization of the ACL service messages with frequent corrections given by the "disregard" message should be limited.

Though more than 300 kinds of CPDLC messages have been defined in the ICAO SARPs (Standards and Recommended Practices) [1], it is assumed to use the message set size of only about 1% in this simulation. However, this setting is not unrealistic, since the frequency change instruction in area control ATC operation has been executed for all the handling aircraft, and the flight altitude change instruction has been frequently executed for the taking off and landing aircraft, and it is considered that these message services are expected to show good effects as the result of the introduction of CPDLC. The flight direction change instruction as the ACL service message is also used frequently for spacing control between aircraft.

Three kinds of simulation scenarios, A, B and C, were prepared for this CPDLC/ATC simulation experiment. Each scenario can be processed in about 30 to 40 minutes. Aircraft density of 45 aircraft per hour is assumed in these scenarios, since allowable process capacity of the Kanto-North sector is 50 aircraft per hour. The characteristics of each simulation scenario are as follows:
  Scenario A – relatively uniform aircraft density
  Scenario C – temporarily high aircraft density
  Scenario B – intermediate between Scenario A and C

Each scenario can be processed without difficulty, if the participant of ATC controller role had ATC service experience at the Kanto-North sector.

In all three scenarios, the percentages of aircraft which have CPDLC capability were set at 0%, 30% and 80%. 0% means the current ATC situation before the introduction of CPDLC into ATC operations, 30% means the introductory phase of CPDLC, and 80% means that all aircraft except military aircraft have CPDLC capability.

As a result of setting the conditions of this simulation, it was decided that each participant playing the ATC controller role should execute nine simulation experiments. Each participant, as a matter of course before the actual simulation, had performed the exercise practice to experience the CPDLC operation carefully.

4. SIMULATION RESULTS AND CONCLUSION

Ten retired ATC controllers belonging to ATCAJ (Air Traffic Control Association, Japan) participated in the role of ATC controller in the CPDLC/ATC simulation. And valid results were obtained from eight participants.

Figure 10: Total Communication Time vs. Rate of Aircraft with CPDLC Capability
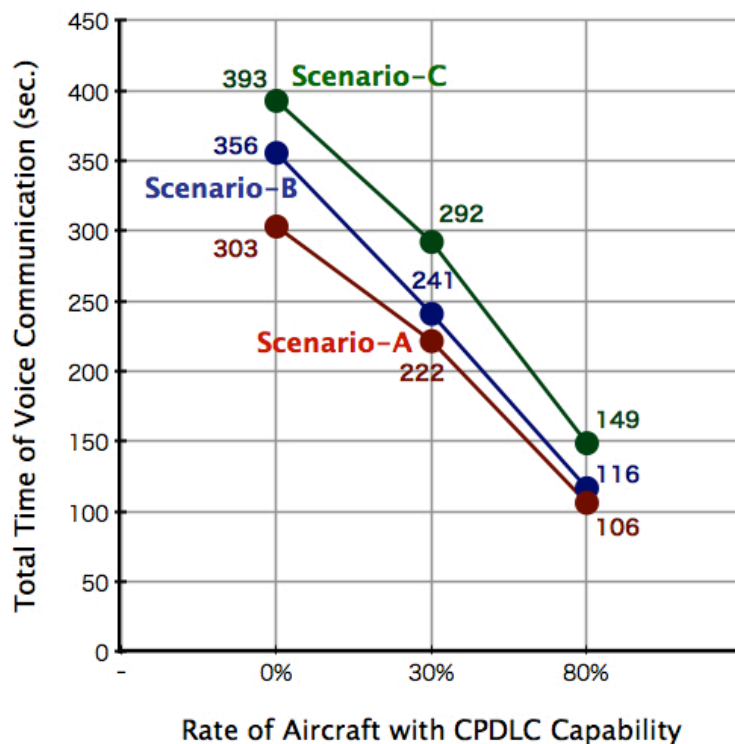

Figure 10 shows the decreasing effect of total voice communication time per scenario by the average value of 8 valid participants.

When the simulation results of each participant playing the ATC controller role is observed respectively, there was a case that the difference of total communication time was more than 100 seconds depending upon the scenario. The average of total time of voice communication decreased as naturally expected according to the increase of the rate of aircraft with CPDLC capability. In particular, the frequency change instruction as the ACM service message was effective to decrease communication time. Conventionally, in analog radio voice communication, it took more than several seconds to give the instruction of the communication frequency change. After the introduction of

CPDLC into domestic ATC operations, the frequency change instruction is instantly completed with a key pack and/or pointing device such as a mouse, etc.

When the percentage of aircraft with CPDLC capability was 80%, there were many positive comments and opinions about the introduction of CPDLC after the simulation experiments, such as follows:
1. Communication time became shorter and the margin occurred during thinking time.
2. It was easier for ATC operations to concentrate.

When it was 30%, the instructions were given almost by conventional analogue radio voice, and there were many negative comments and opinions, such as follows:
1. There were many ATC instructions given by voice to aircraft with CPDLC capability.
2. There was some confusion about the discrimination between aircraft with CPDLC capability and those without the capability.
3. It was not easy to distinguish between aircraft with CPDLC capability and aircraft without the capability, only according to the slight difference in displayed aircraft symbols.

It can be thought that some ATC controllers think "It's useful if air traffic volume is small, but it is necessary to limit the use of ACM service to only when traffic volume is large." No one can tell how the rate of aircraft with CPDLC capability will change in the future, after the introduction of CPDLC into air route ATC operations. It does not seem to be desirable from a viewpoint of an ATC operation workload that the situation of 30% of aircraft with CPDLC capability continues for a long term.

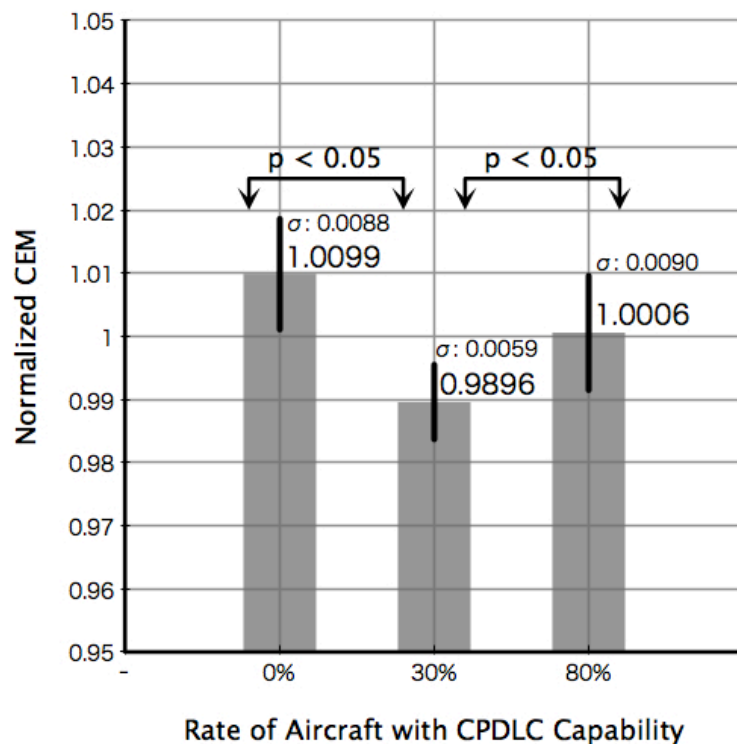**Figure 11: CEM vs. Rate of Aircraft with CPDLC Capability**

Figure 11 shows the relationship between the percentages of aircraft with CPDLC capability and the average of CEM (Cerebral Exponent Macro) values that were calculate from a human voice and correlate with mental load of the speaker [3, 4]. Every CEM value was calculated from every two seconds ATC communication voice by using the software of implementation of SiCECA (Shiomi's Cerebral Exponent Calculation Algorithm) [4, 5].

In 1998, S. Hirose and K. Shiomi found that the time-averaged value of the first Lyapunov exponent calculated from a human voice changed according to the speaker's psychosomatic condition [2]. The

ENRI (Electronic Navigation Research Institute) has then been studying ways of measuring human performance by analyzing a person's voice since 1998.

Figure 11 is the result of research and development of the workload measurement method according to the voice analysis method mentioned above. The CEM value calculated from normal reading voice decreased, when operators were mentally exhausted. In other words, the CEM value indicates the degree of arousal level. However, even when the arousal level is high, if it is necessary to perform more important work than speaking or calling, the CEM value calculated from the utterance as a secondary task decreases, since the processing capacity of the human brain is finite.

Since there is no situation in which the ATC controller becomes sleepy in every simulation scenario, it is thought that the decrease of the CEM values depends on the increase of thinking work. The Student's t-test was used for comparison between the "0% case" and "30% case" groups, and the "30% case" and "80% case" groups. A probability value $p < 0.05$ was considered statistically significant. As the results of analysis of the communication voice of ATC controllers, Figure 11 shows that the ATC workload increases under the condition that the aircraft with CPDLC capability and conventional aircraft without the capability are intermingled. It is then confirmed that the ATC workload is not simply dependent on the length of communication time.

Acknowledgements

References

[1] http://www.icao.int/safety/SafetyManagement/Pages/SARPs.aspx.
[2] K. Shiomi and S. Hirose, *"Fatigue and Drowsiness Predictor for Pilots and Air Traffic Controllers"*, Proc. of 45th Annual ATCA Conference, Oct. 2000, U.S.
[3] K. Shiomi and et. al., *"Experimental Results of Measuring Human Fatigue by Utilizing Uttered Voice Processing"*, Proc. of IEEE-SMC 2008, P557, Oct. 2008, Singapore.
[4] K. Shiomi, *"Voice Processing Technique for Human Cerebral Activity Measurement"*, Proc. of IEEE-SMC 2008, P660, Oct. 2008, Singapore.
[5] K. Shiomi, *"Chaotic Voice Analysis Method for Human Performance Monitoring"*, Proc. of ESREL2009, Sep. 2009, Prague, Czech Republic.