PC TOOL DEVELOPMENT FOR SIMULATING FLIGHT MANAGEMENT PROCESS OF JET AIRLINER PILOTS

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Abstract

Airline pilots operating scheduled flights must consider flight safety, economical use of fuel to minimize expenditure, punctual flight operation, and passenger comfort. In this paper, we use the term "flight management skill" to denote an operational skill that takes the above-mentioned factors into consideration. Research into flight management skill is limited because of high experimental costs and the availability of full-flight simulators. In order to perform flight management skill research easily, we have been developing a PC tool. The main feature of this PC tool is that it not only displays a simplified flight situation, but also records and displays the operation history as a time-series table. The PC tool does not reproduce all the components of the actual flight; we have to extract the significant factors that affect the decision-making process in an actual flight. For examinees to be able to obtain information on the flight conditions easily, the design of the PC tool interface is important. This paper demonstrates the results obtained using different styles of PC tool interface, and the discussion suggests interface guidelines. Studies have been conducted with airline pilots using the scenario of Haneda Airport runway closure due to an earthquake. We have also conducted experiments for the same scenario using a full-flight simulator. The experiments showed that essentially the same results were obtained using the PC tool and the full-flight simulator with regard to differences in decision making between inexperienced and experienced pilots.

1 Introduction

1.1 Background

Progress in human-centered aircraft automation systems [1], such as development of autopilot navigation systems, horizontal situation indicators with traffic alert and collision avoidance systems (TCAS), digital data links for air traffic control (ATC), has decreased the number of procedures airline pilot are required to perform. These procedures are automated and simplified, so pilots can manage normal flights with no or very little difficulty in decision making. Even in dealing with an emergency situation, for example, an engine fire, the crew simply follows the non-normal checklist and the procedure itself involves no decision-making process as long as attention is focused on removing the non-normal situation [2].

According to data from Boeing Commercial Airplanes on worldwide commercial aviation accidents in 2008, 58% of accidents occurred in the initial approach, final approach, or landing phase, and 30% were runway excursions [3]. In order to decrease human error, crew resource management (CRM) training, which is essential to flight safety, has been introduced [4]. There have been many studies of human error in non-normal situations [5–7]. Line-oriented flight training (LOFT) [8], which has the overall objective of improving total flight crew performance, prevents incidents and accidents during operational flying. LOFT gives the opportunity to practice line operations (e.g., maneuvers,

operating skills, systems operations, and operators' procedures) and CRM skills (e.g., crew coordination, judgment, decision making, and communication skills) in a realistic environment.

In the case of trivial failure in a normal flight, flight operation depends on the pilot's flight management skill. For example, in the case of a sudden runway closure, pilots have many choices, and usually none of the solutions leads to a serious crisis. It is desirable for pilots to reconstruct their flight plan giving consideration to the following four factors:

1) flight safety,
2) punctual flight operation,
3) minimizing fuel consumption,
4) passenger comfort.

As a matter of course, flight safety should be maintained at an extremely high level. Pilots should also maintain the other factors at high levels.

In this paper, we use the term "flight management skill" to signify the risk-management ability to cope with sudden changes in flight conditions, while ensuring flight safety, maintaining schedule punctuality, saving fuel, and maintaining passenger comfort. At present, the management skills of an airline pilot, which are considered to be non-quantitative experience-based skills, are acquired from the individual's own experience during actual flights. Airline companies are keen for such experience-based skills to be clarified and explicitly defined in order to improve pilot training systems, and increase customer satisfaction.

There have been only a few previous studies researching how airline pilots use their judgment to manage difficult situations during normal flight operation. Baker et. al. [9] developed PC-based training tools to teach CRM skills in normal flight operation. In their scenario, one of the passengers began to complain of chest pains. The crew had to decide what to do and where to go next. Ide et. al. [10] has conducted full-flight simulator experiments and clarified the difference in the flight management skill of experienced captains and those of novice copilots, using the scenario of sudden runway closure due to an earthquake.

The experimental results demonstrated that inexperienced pilots tended to divert quickly to other airports, whereas experienced pilots tended to keep holding while their remaining fuel margin was adequate.

1.2 Objectives

In researching flight management skill, we have to carry out a sufficient number of experiments. However, the high experimental cost and the availability of full-flight simulators make this difficult. In order to perform flight management skill research easily, we have developed PC software that displays a simplified flight situation and records the operation history. The obtained time history of the operation is represented as a time-series chart, which is used for operation analysis.

To acquire the ability to deal with sudden events, real-time training using equipment that closely simulates a real flight is considered to be effective. Training using full-flight simulators is best with regard to simulating reality, but the cost of conducting such training is very high, and availability is limited because there are many trainees. On the other hand, teaching flight management skill by providing information as printed handouts cannot simulate real-time situation awareness and alternate planning (Fig. 1). Baker et. al. conducted research using inexpensive desktop computer-based simulations as CRM training media with military aircrews.

The aim of this paper is the development of a PC tool which not only simulates real-time real flights in real-time in a simplified style, but also visualizes and quantifies the decision-making process. Adding the visualization feature enables the differences between experienced captains and novice copilots to be displayed quantitatively, enabling an effective training method to be developed. This paper demonstrates the results of experiments that were carried out using the PC tool, which has a scenario the same as that in full-flight simulator experiments. This paper also demonstrates the operational differences between experienced and novice pilots.

2 Experimental Details

2.1 Overview of PC tool

Fig. 2 is a screenshot of the flight management PC tool. The program is started by clicking on the Start button at the lower left of the screen. Operation of the airplane is represented by clicking on the button displayed in the cockpit region. The message that was reported to the cockpit is displayed in the white rectangle in the cockpit region, and sounds are played simultaneously with the display.

A horizontal situation indicator (HIS) is displayed at the lower left of the screen. The position of the airplane can be recognized from the HIS display. The checklist, which is executed after the series of operations, is shown at the upper right of the screen. A check mark is displayed by clicking an item on the checklist. When all items have been checked, a "Checklist Complete" message is displayed.

Communication with the ground is imitated by the management region in the upper left of the screen. In the case of full-flight simulator experiments, examinees use radio to communicate with air traffic control (ATC) and company radio in order to get information on runway conditions, weather, alternate fuel, etc. at the destination and at other airports. However, in the PC tool case, it is hard to distinguish what is being asked using voice recognition systems. The examinees therefore have to type their question using the keyboard or have to select a choice from a keyword list.

In the management region, there are three input cells, named "Who", "Where", and "What" and an [Ask] button. The "Who", "Where", and "What" cells correspond to selection of the target (ATC, company), place (RJTT, 5000 ft, etc.), and question (alternate fuel, runway information, etc.), respectively.

Two types of interface, namely blank cell and list of choices, are settable for the cells. In the blank cells case, the examinee should input keywords using the keyboard. If the keywords do not match the registered data, the message "Check Input Data" is displayed. In the list of choices case, the examinee only clicks on the keywords from the list. In the former case, the examinee cannot get enough of the information necessary for flight management when the keywords do not match the entered data. In the latter case, the examinee could predict the scenario from the list of choices. A certain time after clicking the [Ask] button, the answer is displayed with the sound of a voice.

In order to record the examinees thoughts during the experiment, comments can be input in the comment region using the keyboard. When the scenario reaches the termination phase, the message "Experiment has finished" is displayed.

The obtained operation time-history is instantaneously visualized as a time-series chart; a screenshot is shown in Fig. 3. The visualization tool is used for analysis of the operation.

We should bear in mind that operation of the PC tool is different from operation of a real-flight simulator, and the level of proficiency in using the PC tool affects the experimental results. When reading the documentation for the operation before the experiment, it is possible that examinees might skip part of the description. We therefore use a PC tool tutorial, which enables the operation to be practiced using audio guidance before the experiment. The merit of this feature is that it makes the level of proficiency as constant as possible because the tutorial never skips the explanation, and runs through all the operations.

2.2 Airport Information

Haneda Airport (RJTT), which is located 14 km south of Tokyo station, is used mainly for domestic flights. Haneda Airport handled approximately 61 million domestic flight passengers in 2008 [11]. Narita airport (RJAA), which is located 57 km east of Tokyo station, is used mainly for international flights. Narita Airport handled approximately 32 million international flight passengers in 2008 [12]. In both airports, the total number of flights has already reached maximum capacity.

Comparison of these figures with the total number of domestic flight passengers, which was approximately 93 million, shows that two-thirds of domestic flight passengers used flights

from or to Haneda Airport. The flight destination was generally more than 500 km from Tokyo, mainly because of competition from Shinkansen (high-speed train). As a consequence, alternate airports like Chubu (RJGG) or Sendai (RJSS), which are approximately 300 km from Tokyo, are relatively little used compared with Haneda and Narita airports.

2.3 Scenario

The scenario flight conditions are summarized in Table 1. The remaining fuel is sufficient for a flight duration equivalent to 30 min holding and diverting to an alternate airport. The flight experiment starts two nautical miles from the final approach (Tokyo RJTT ILS No. 2 Rwy 34R procedure, see Fig. 4). The examinees are assumed to be a PF (pilot flying) and a PIC (pilot in command). They operate the PC tool themselves because no PNF (pilot not flying) attends the examination.

The destination airport is RJTT, and the alternate airport is RJAA. Other airports that are considered to be suitable alternates are RJGG and RJSS. Fig. 5 shows the location of the destination and alternate airports.

The initial conditions, shown in Table 2, are available as a printout, and this document is given to the examinee before the beginning of the experiment. Fuel flow in the holding state is 140 lb/min. The amount of alternate fuel that the company tells the pilots is available is fixed as shown in Table 1, regardless of the weather and the weight.

The assumed weather at each airport is also shown in Table 1. The runway visual range (RVR) of RJTT is 1800 m and is above the prescribed RVR value for ILS approach. However, if a glide slope is not serviced and the pilot is forced to shoot a localizer approach, the RVR value corresponds to the "Just Minimum" condition. The first alternate airport, RJAA, has relatively better weather conditions. The other alternate airports (RJGG and RJSS) are in a "Ceiling and Visibility OK" (CAV OK) condition, which means there is no problem concerning weather conditions.

The scenario setting is shown in Table 3. The scenario used in the experiment is essentially the same as that used in the previous study using a flight simulator [10]. When the altitude was around 200 ft, go-around was called due to an earthquake.

The estimated time until the runway could re-open was uncertain. At this point two choices were possible: (A) diverting immediately to the alternate airport or diverting after a short holding time; and (B) holding until the information that the RJTT and RJAA runways would be re-opened was received.

As time passes, information on the runway conditions, which is reported by company radio, changes, as shown in Table 3. Approximately fifteen min after the runway closure, the airport opened under the conditions that glide slope was disabled and localizer approach was enabled. The experiment finishes when the examinee decides whether to land at the destination airport or at an alternate airport.

2.4 Questionnaire investigation

The thinking process during the experiment and the main motivation for the final decision were clarified using a questionnaire. The questions clarify the final airport selection, the timing of the final decision, the reasons for the judgment made, recognition of the situation at each airport, and so on.

3 Results

3.1 First version of the PC tool: commands to be typed in using the keyboard

In this case, the "Where" and "What" cells in the management region are set to display only a limited choice, and other requests should be typed in the blank space using the keyboard. The main aim in setting the choices is that the examinee cannot predict the scenario from the list of choices. In the "What" cells, the choices shown are "WEATHER", "RUNWAY", "LANDING", and "DIVT". We have also prepared answers corresponding to "ALTERNATE FUEL", "WIND", "TRAFFIC",

and "HOLD". In the "Where" cells, the choices given are "RJTT" and "RJAA"; other airports such as "RJGG" and "RJSS" are not shown. When the examinee chooses "DIVT", the program is terminated so that the airport is recognized as a final decision.

In the questionnaire, some examinees said that they still wanted to continue information collection; however, the input keywords did not hit the registered data, and they tentatively selected the choice "DIV". The PC tool showed the airport as their final decision, but the results were different from their intention.

The results were rechecked, excluding the data from questionnaires which stated that the intention was different from the airport recorded by the PC tool. The total number of examinees was 39; 17 had recorded improper data and were eliminated, and only 21 had recorded the proper data, as shown in Table 4(a). It should be mentioned that the number with improper data is remarkably high. Table 4(a) also shows the airport finally selected and the decision-making time, which is divided into the above-mentioned two choices (A) and (B).

The airport selected as their final decision is classified by pilot flight experience in Fig.6(a). This is roughly divided into (A) RJGG and (B) RJTT. Whereas three-quarters of the examinees who selected (A) RJGG had total flight experience of less than 5000 h, two-thirds of the examinees who decided on (B) RJTT had total flight experience of more than 5000 h, or were captains.

The experimental study conducted with a full-flight simulator demonstrated the tendency for experienced pilots to wait until the runway re-opened, whereas novice pilots quickly diverted to alternate airports. In this regard, the results between the full-flight simulator and the PC tool were similar.

3.2 Second version of the PC tool: commands can be selected from a list of choices

In the case of the second version of the PC tool, the final decision was judged by selecting "REQ AIRWAY CLEARANCE," and the PC tool was terminated by this request. In order to make it easy to obtain the information, all of the keywords were shown in a list in the "What" cell: "WEATHER", "RW INFO", "REQ AIRWAY CLEARANCE", "ALTN FUEL", "WIND", "VISIBILITY", "TRAFFIC", "ESTIMATED REOPEN", "REQ SPOT No", "APCH SEQUENCE", "NOTAM", "REQ APCH CLEARANCE", "ALTITUDE REQ", "SPEED REQ". These keywords were chosen from the results of the questionnaire obtained in the examination using the first version. Displaying a considerable number of choices also has the merit that it is not easy to guess the scenario.

In contrast, the "Where" cell showed only "RJTT" and "RJAA" in the list of choices, and all of the other keywords had to be typed. In the "Where" cell, variations in the entries are limited; airports are generally specified by a four-letter code, and altitude and speed requests are specified by numbers.

As in the case of the first version, we have excluded data where the examinee commented in the questionnaire that their intention had been different from the airport recorded. As shown in Table 4(b), the total number of examinees was 14; 13 data recorded the proper data, and only one was eliminated as improper data. The reduction in the amount of improper data recorded indicates that presenting a list of choices in the "What" cell is a better interface for the PC tool.

It should be mentioned that, comparing Fig. 6(a) and Fig. 6(b), the percentage of examinees who selected (A) RJGG is higher in Fig. 6(b). In the questionnaire, the following comment was found: "Diverted to RJGG because the remaining fuel reached the limit." Analysis of flight operation logs and questionnaires also showed that, as shown in Table 5, examinees whose total flight experience was less than 3000 h decided to divert within 10 min, whereas those with more than 3000 h waited until the RJTT and RJAA runways is going to be re-opened. They did not obtain the information that RJTT would be re-opened and diverted to RJGG without receiving the information whether RJTT was re-opened or not.

Because of the PC tool setting, the examinees had to contact ATC or the company radio to obtain information on RJTT re-opening.

In the questionnaire, it was pointed out that the PC tool becomes closer to an actual flight if the runway information is automatically notified from ATC. It is expected that, if the information on RJTT re-opening is automatically reported, the number of examinees who are classified as (B) RJTT will increase.

3.3 Latest version of the PC tool: information on RJTT re-opening is automatically reported

To improve the PC tool operation so that it more closely simulates an actual flight, and to confirm the discussion of the results of the second version, the PC tool has been modified so that information on the re-opening of RJTT is automatically reported. Table 4(c) shows that all of the data were retained as proper data, and no data were eliminated as improper data. Fig. 6(c) indicates that some inexperienced examinees were classified as (B) RJGG, which means that the examinees keep holding until they received the information that RJTT would be re-opened but they decided to divert to RJGG. The total flight experience of examinees that chose RJGG was less than 5000 h, and mainly less than 1000 h. On the other hand, the examinees who were classified as (B) RJTT and (B) RJAA had flight experience of more than 5000 h, or were captains.

Novice copilots tended to divert to RJGG and experienced captains tried to land at the airport close to the destination. In this regard, the results are consistent with those using full-flight simulators.

3.4 Questionnaire research results classified by flight experience

The results of the survey by questionnaire were analyzed. Answers that show the different tendencies by flight experience are shown in Fig. 7. The results from the second and the latest versions of the PC tool are combined because automatically reporting information on the re-opening of RJTT does not affect awareness of the situation.

(a) Try RJTT at "Just Minimum"

All of the captains answered "Try" , whereas some of the copilots answered "Cannot Try" .
(b) RJTT sequence priority
The rate of "Divert Early" is higher for copilots than for captains.
(c) Worried if the weather at RJAA worsened
The rate of "Range of visibility 5000 is sufficient" is higher for captains than for copilots.
(d) Similar experience in the past
The copilots were more strongly influenced by past experiences than the captains were.

From the results shown in Figs. 7(a)–(c), we can conclude that the differences in situation recognition by captains lead to a strong tendency to land at RJTT. It is conceivable from Fig. 7(d) that pilots with longer flight experience have encountered a greater variety of situations than novice pilots, and they may not be strongly influenced by any individual experience. This agrees with discussions of naturalistic decision making in aviation environments [13]. Experts can identify underlying causes of problems and have deeper, more complex models and understanding of the problem and the environment, whereas novice pilots simply will not have enough templates of situations, encounters, or circumstances in their memory to match the pattern of the current situation.

If experience gained from the scenario using the PC tool builds situation templates, it will help novice pilots to build decision-making models that reach the level of the expert. In future, we will add other scenarios to the PC tool so that we can simulate various flights situations.

4 Conclusions

A PC tool that imitates a simplified flight operation and records the operation history has been developed. The software also visualizes the decision-making process as a time-series chart of the operation history. Experimental studies carried out using the PC tool, and studies using a full-flight simulator, demonstrated essentially the same result with regard to the differences in the "flight management skill" of

experienced captains and that of novice copilots. Experienced pilots tended to wait until the runway re-opened. The experimental study using the revised PC tool, with modifications such as automatic notification of runway re-opening, showed the best results with regard to reducing the amount of improper experimental data. The thinking process during the simulated flight was clarified by analysis of a questionnaire. The captains' situation recognition led to a strong tendency to land at RJTT. Copilots were more strongly influenced by past experience than captains were. If the experience gained using the PC tool builds situation templates, it will help to build the decision-making models of novice pilots to the level of the expert.

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Table 1 Airport scenario settings

	Airport			
	Haneda (RJTT)	Narita (RJAA)	Chubu (RJGG)	Sendai (RJSS)
Required Time	------	35min	50min	55min
Alternate Fuel [lb]*	------	7000	9000	10000
Influence of Earthquake	10-15min Runway Check. After that Open at Glide Slope disable & Localizer Approach	10-15 min Runway Check	NIL	NIL
Wind	340°/10kt	350°/15kt	Calm	Calm
Visibility	1800m	5000m	CAVOK**	CAVOK
RVR	1800m***	5000m	CAVOK	CAVOK
Ceiling	500ft	1500ft	CAVOK	CAVOK

*Assumed value in this experiment **Ceiling and Visibility OK ***Just minimum value at glide slope disable

Table 2 Initial flight conditions

Flight Number	ANA 602	Aircraft	B767
Setting at Scenario Beginning		Weather Info.	
Ground Speed	134kt	Destination	RJTT (Haneda)
Altitude	MSL 1600ft	340/10KT 1800 OVC007 15/7 2992 (Current)	
Rate of Descent	650ft/min	Alternate	RJAA (Narita)
Remaining Fuel	18000lb	350/15KT 5000 OVC015 15/8 2992 (Flight Plan)	
Gross Weight	240000lb	FUEL PLAN	
Scenario Begins at		ALTERNATE FUEL to RJAA 7000lb/36min	
RJTT/ILS RWY 34R Final Approach Course		RESERVE FUEL 4000lb/30min	

Table 3 Scenario setting

Time	Information
Approach (Aroud Decision Height)	Go Around due to Earthquake.
Within 10 min after Go Around	Earthquake Reported throughout the Kanto district. Earthquake intensity is 5 lower. RJTT and RJAA are in runway check for 10-15min.
After 10 min from Go Around	RJTT and RJAA will re-open soon. RJTT: RWY34R LOC APP, other RWY un-service. RJAA: No damage.
Around 15 min after Go Around	RJTT and RJAA runway re-open.

Table 4 Experimental results using PC tool

(A) Command of communication should be typed in using keyboard

Examinee Nunber	39	Decision of Proper Data	RJTT	RJAA	RJGG/SS
Proper Data	21	(A) Before RJTT will re-open	-	1	8
Improper Data	17	(B) After RJTT will re-open	9	2	1

(B) Command of communication should be selected from the list of choice

Examinee Nunber	14	Decision of Proper Data	RJTT	RJAA	RJGG/SS
Proper Data	13	(A) Before RJTT will re-open	-	0	8
Improper Data	1	(B) After RJTT will re-open	4	1	0

(C) Information of RJTT Re-open is automatically announced

Examinee Nunber	14	Decision of Proper Data	RJTT	RJAA	RJGG/SS
Proper Data	14	(A) Before RJTT will re-open	-	0	2
Improper Data	0	(B) After RJTT will re-open	6	4	2

Table 5 Divert decision time of examinees classified as (A) RJGG

Divert decision time before	10 min	15 min
Captain	0	2
Copilot: Flight time over 3000 h	0	3
Copilot: Flight time under 3000 h	3	0
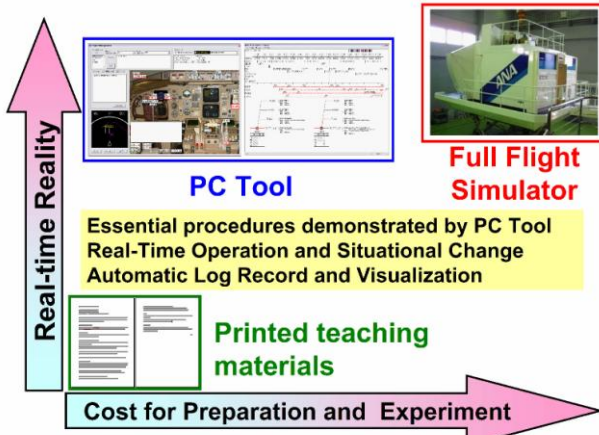
Fig. 1 Aim of the PC tool
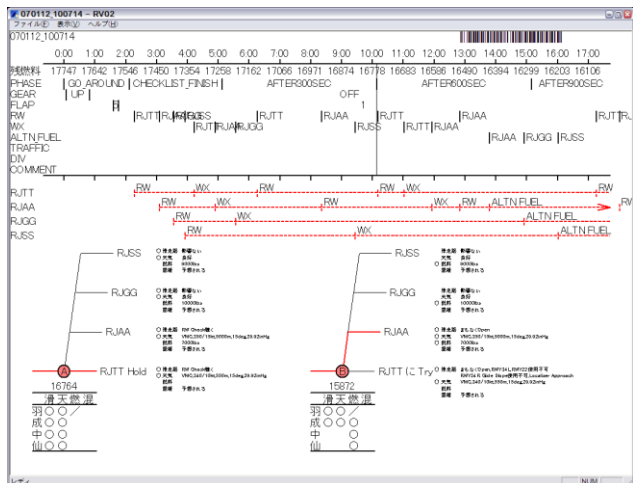

Fig. 2 Screenshot of the
Flight Management PC tool
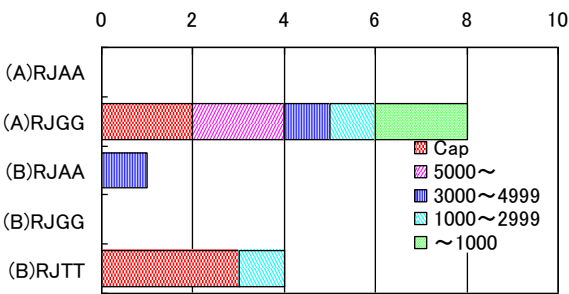

Fig.3 Time-history view of the operation record

STRAIGHT−IN LANDING RWY 34R	
ILS	LOC (GS out)
DA 220' (200')	MDA 700' (679')
FULL	
RVR 550m	RVR 1800m
VIS 800m	

Fig. 4 HND ILS RWY 34R approach chart
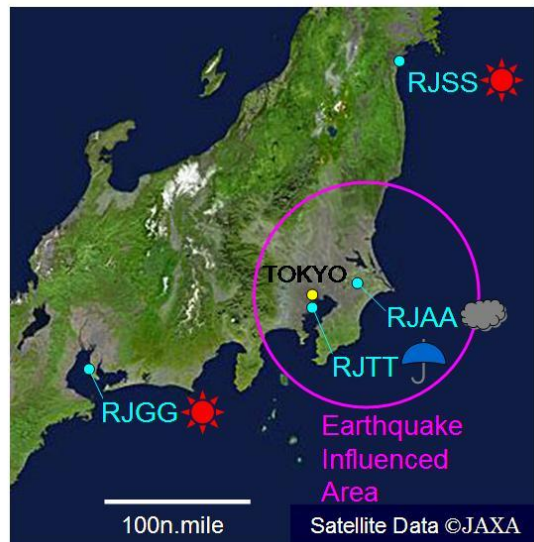
Fig. 5 Satellite map of the destination and
alternate airports
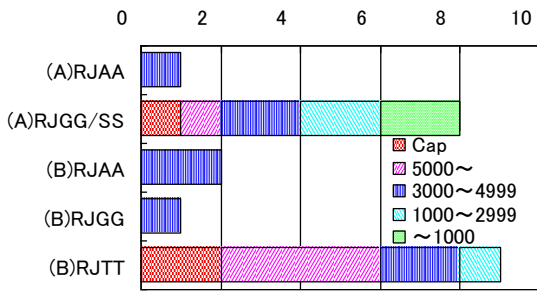
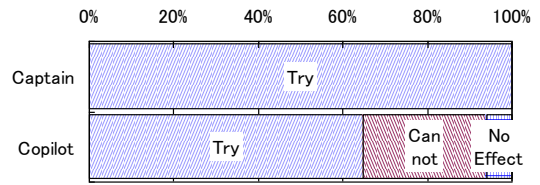(a) Commands should be typed in by keyboard
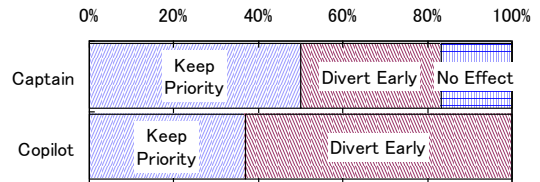
(b) Commands can be selected from list of choice
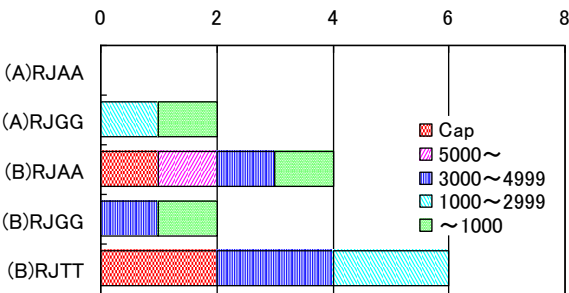
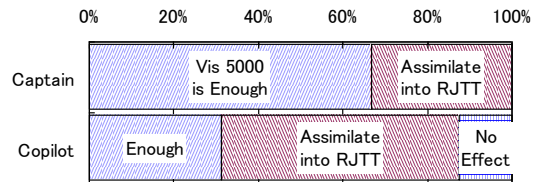(c) Information on RJTT re-opening is automatically reported

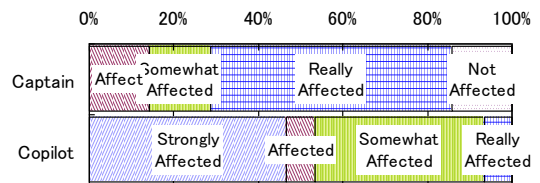Fig. 6 Selected airports as a final destination

(a) Try RJTT at "Just Minimum"

(b) RJTT sequence priority

(c) Worried if the weather at RJAA worsened

(d) Similar experience in the past

Fig. 7 Answers which show different tendencies by flight experience