A Design Method of Information Display for Pilot Support with Emphasis on Resilience in Highly Automated Flight Deck

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Abstract. For achieving higher level of safety and efficiency in aviation, advanced automated systems in a flight deck have played important roles. However, the increasing system's autonomy and complexity which brought by highly automation can be a cause of difficulties in the human-machine coordination. Loss of appropriate situation awareness (SA) is typical example of this kind of difficulty, which is considered as a potential factor leading to an accident. In the present study, a method to improve HMI has been proposed with the emphasis on the analysis of cognitive resources actually utilized in complex task environments. A prototype information display for the advanced flight deck has been developed based on the proposed method and the validity of the proposed method has been evaluated through a simulation-based experiments.

1 INTRODUCTION

For achieving higher level of safety and efficiency in aviation, advanced automated systems in a flight deck have played important roles. An introduction of autopilot system has contributed to the operations in adverse weather conditions and to improved punctuality and also to the reduction of human errors. Meanwhile, it has been pointed out that the increased system's autonomy and complexity can be a cause of difficulties in the human-machine coordination [Woods, D. D., 1996, 3-17] [Javaux, D., 1998, 62-77]. Loss of appropriate situation awareness (SA) is typical example of this kind of difficulty, which is considered as a potential factor leading to an accident. The importance of the role of Human-Machine Interface (HMI) to support pilots to maintain correct SA has been pointed out in previous researches [Vicente, K. J. & Rasmussen, J., 1992, 589-606] [Kelly, B. D., 2004, 3-31].

Although the importance of the HMI for achieving higher level of safety has been recognized, the design modification process for HMI in terms of supporting pilot's SA has been driven by hindsight lessons derived from common or salient cases of past accidents and incidents, or by user requirements which are well-defined and clearly describable in separated conditions from an actual field. The authors consider that more effort should be made to realize proactive and preventive improvement of HMI.

The present research has explored a proactive improving method of HMI for supporting operators' SA taking a flight deck display as an example. It is considered that experienced operators and organizations composed of these experts that operate large-scale complex systems like aircrafts build up a kind of practical knowledge for achieving safe and efficient operation. The knowledge takes various forms as explicit resources (e.g. operating procedures, related documents) or as implicit resources (e.g. operators' know-how for safe and efficient operation, custom or culture in a field), which has been adapted to compensate for inadequacies of existing systems and to help operators to maintain appropriate situation recognition [Miller, T. E., 1997, 141-149] [Hutchins, E.

& Klausen, T., 1996, 15-34] [Hutchins, E., 2002]. In other word, those are sources of resilience that allow operators to maintain sensitive to the possibility for failure. The authors believe that analyses of cognitive resources in a field as integration of practical knowledge can bring out important suggestions to proactive and preventive improvement of HMI.

In the present study, a method to improve HMI has been proposed with the emphasis on the analysis of cognitive resources actually utilized in complex task environments. A prototype information display for the advanced flight deck has been developed based on the proposed method and the validity of the proposed method has been evaluated through a simulation-based experiments.

2 ANALYSIS OF COGNITIVE RESOURCES

In this chapter, the analysis results on explicit and implicit resources in a field of flight operations are described to decide information contents to be indicated on the display.

2.1 Procedure of Analysis

The analysis was performed based on the following procedures.

(1) Analysis of resources in a field of line operation
(2) Interview with an expert pilot
(3) Open-ended questionnaire to three airline pilots

Firstly, the analyses of following materials were performed, which are routinely utilized in a line operation.

- Company clearance
- Navigation log
- Standard Instrument Departure (SID) chart
- Approach chart (describing Standard Terminal Arrival Route (STAR) and related information)

A company clearance contains information about departure, arrival, alternate airports, expected flight hours, burnout fuel, predicted takeoff weight, and so on. A navigation log indicates flight planed route, list of passing waypoints and the estimated time of arrival of each waypoints, distance between two waypoints and the required flight time, and so on. Pilots take these materials in advance before boarding their aircraft. SID and Approach chart mainly describe predetermined departure and approach route with information of altitude restrictions. Pilots refer to these charts in departure or approach phase.

In addition to the above mentioned written materials, standardized contents of cockpit crew’s briefings which are required to perform at the specific point during the operation were analyzed.

- Take off briefing (which is performed in pre-departure preparation)
- Landing briefing (which is performed before starting descent)

Based on the analysis of these resources, hypothesis concerning cognitive resources, described in the following section, has been specified, which provide resilience to failures. The validity of the hypothesis was evaluated through the interview with an expert pilot and open-ended questionnaire to three airline pilots.

2.2 Result

The result of the analysis of the resources described in section 2.1 has indicated that those resources are utilized to support pilots to construct mental image which represents in-flight situations and operations in advance.

For example, in a company clearance, information concerning Reaching Cruise Altitude (RCA) point and End Of Cruise (EOC) point has been explicitly described although pilots can obtain the same kind of data calculated by Flight Management System (FMS) in a flight deck (show Fig. 1). In addition, SID charts and approach chart show graphical images of flight path although most of such images are also available graphically on a flight deck display (show Fig. 2). Moreover, the standardized contents of takeoff and

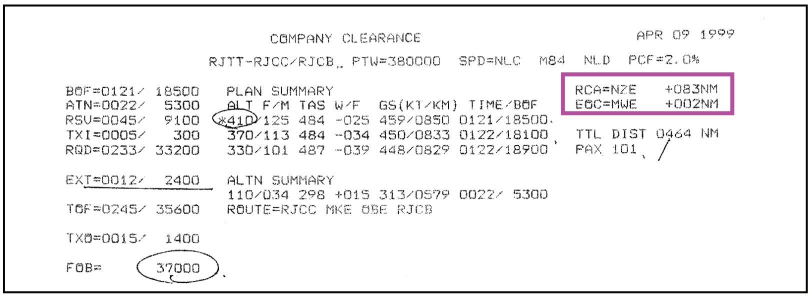
COMPANY CLEARANCE APR 09 1999
RJTT-RJCC/RJCB PTW=380000 SPD=NLC M84 NLD PCF=2.0%
BOF=0121/ 18500 PLAN SUMMARY RCA=NZE +083NM
ATN=0022/ 5300 ALT F/M TAS W/F GS(KT/KM) TIME/BOF EOC=MWE +002NM
RSV=0045/ 9100 *410/125 484 -025 459/0850 0121/18500
TXI=0005/ 300 370/113 484 -034 450/0833 0122/18100 TTL DIST 0464 NM
RQD=0233/ 33200 330/101 487 -039 448/0829 0122/18900 PAX 101
EXT=0012/ 2400 ALTN SUMMARY
110/034 298 +015 313/0579 0022/ 5300
TOF=0245/ 35600 ROUTE=RJCC MKE OBE RJCB
TXO=0015/ 1400
FOB= 37000

Fig. 1. Example of Company Clearance [Takeda, K, 2000, 10]

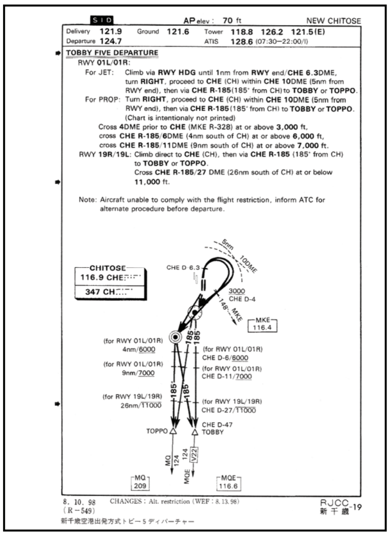

Fig. 2. Example of SID Chart [Takeda, K, 2000, 108]

landing briefing has items for confirming flight procedure in normal and off-normal situations following flight sequence such as passing waypoints, altitude and speed restrictions, and relating procedural operations.

Based on previous results, the following hypothesis has been specified.

<Hypothesis> Pilot constructs mental image which represents in-flight situations and operations in advance, and utilizes it as a reference for detection of a possible risky situation in its early stage.

For validating this hypothesis, an interview with an expert pilot and open-ended questionnaires to three airline pilots were performed. In the interview, the expert pilot mentioned his practice to have made a diagrammatic sketch of vertical and lateral flight plans by himself before flying new routes to memorize the flight procedure in advance. This fact strongly indicates the importance of flight image. The results of questionnaire to three airline pilots has also support the hypothesis. As described in Table 1, each of three pilots has affirmed the necessity and importance of flight image. In addition, two pilots used the term of image-flight, which implies that importance of flight image are commonly recognized by some of airline pilots.

Although the further analysis is required to evaluate the generality of the hypothesis, it is at least consistent with our observation and it can be utilized as the basis for design procedure for HMI.

Table 1. Parts of Questionnaires and Answers

(Original questionnaires and answers are written in Japanese)

Q1	Do you construct general image of the flight before the actual flight operation? Do you remember it?
Pilot A	As almost remembering flight procedures of accustomed domestic airports, I can enough confirm flight procedures of such airports in a briefing. However, in the cases of inexperienced foreign airports, I review the flight procedure in the previous day of the flight or in the cursing phase.
Pilot B	In the case of flying a new route, after confirming precautions, I practice a work following the chart with imaging the actual flight. In addition, I learn operations in the flight by performing *image flights* many times.
Pilot C	I plan aircraft's configurations (speed, altitude, gear , flap and so on) at each point and construct the image. In addition, I perform *image flights* for circling approach.

3 IMPLEMENTATION

The analysis of cognitive resources in a field described in the previous chapter has revealed that pilot constructs mental image which represents in-flight situations and operations in advance, and utilizes it as a reference for detection of a possible risky situation in its early stage. It has a role of resilience to failures by supporting early detection of off-normal situations and providing opportunity to recover from it.

In the present study, a prototype of information display for supporting resilience of experienced pilots' practice has been developed on the PC-based Flight Simulator. The proposed display called Enhanced Primary Flight Display (EPFD) has been designed to support a pilot in detecting possible deviations of his flight image from the actual situation by providing minimum information. It aims at supporting pilot's practice descried in chapter 2. The basic structure of the display is similar to the existing Primary Flight Display (PFD) because pilots are highly accustomed to the existing display form. Some additional information has been introduced in the proposed display as shown in Fig. 3. The information contents displayed on EPFD has been determined based on the results of analysis in chapter 2. For example, the standardized contents of flight crew's briefing such as such as passing waypoints, altitude and speed restrictions have been visualized in EPFD to help pilots to maintain location recognition, and a symbol of target altitude which is set to autopilot systems. When the pilot erroneously set the autopilot and the aircraft departs from the intended flight path, the additional information can be cues for pilots to detect the deviation from the unexpected flight path in its early stage.

Fig. 3. Example of EPFD

4 EVALUATION

In this chapter, the evaluation results are described to validate the effectiveness of EPFD as a supporting display through simulation-based experiment with a human-machine system simulation called Pilot Cognitive Simulation (PCS).

4.1 Pilot Cognitive Simulation (PCS)

We have developed the human-machine system simulation called Pilot Cognitive Simulation (PCS) based on the cognitive model proposed by Endsley [Endsley, M. E., 2000, 16]. It can simulate pilots' attention allocation in a cockpit. A simulated pilot in the PCS has an internal situation model which is separated from actual situation model. This internal situation model determines the behavior of the pilot. The internal model is updated by information obtained from external world and also by predictions based on pilot's knowledge and acquired information. This architecture enables PCS to simulate not only passive monitoring process but also active monitoring process based on predictions.

4.2 EPFD's Implementation to PCS

For simulation-based evaluation of the supporting functions of EPFD, the information provided by the supporting display and its available condition have been modeled based on the design specification of EPFD. The purpose of this simulation-based evaluation by PCS is to assess the effectiveness of EPFD as a supporting display in a crucial situation when multiple human errors occur. The human error rates in information acquisition from EPFD have been assumed to be apparently higher than realistic error rates to emphasize the erroneous situations in which the EPFD may contribute to prevent accident to happen.

4.3 Simulation-based Evaluation

Simulation Scenario: For evaluating possible positive and negative effects provided by EPFD, three kinds of simulation scenarios have been prepared. Each scenario consists of 12 cases of simulation with EPFD and 12 cases without EPFD (same as traditional displays in a conventional flight deck). As simulations by PCS are not deterministic, it is basically required to perform multiple cases of simulation runs and to take the average of those numerical results. The total numbers of cases in this simulation experiment is 72 cases.

Scenario1: An erroneous setting of target altitude happens in performing the emergency descent procedure
Scenario2: An erroneous setting of Flight Management System (FMS) in inputting necessary data into FMS for an unprepared divert
Scenario3: Normal Descent form Cruise Altitude in a line operation

Evaluation Index: The results of this simulation experiment are evaluated based on the following evaluation indexes.

1) Error detection time
2) Information or knowledge which provides cues of error detection to a simulated pilot

4.4 Results of Evaluation (Scenario 1)

Because of page limitations, a part of the results of the simulation-based evaluation are described in this section. The result of error detection time in the scenario 1 is shown in Table 2. The average detection time of erroneous setting of target altitude is 18 sec. with EPFD, which is approximately half the time without EPFD. Through analysis of simulation logs, in 9 out of 12 cases of simulation with EPFD, the pilots detected the error from supporting information by EPFD. These results clearly demonstrate the effectiveness of EPFD as a support of SA in the early stage of potential risky situation.

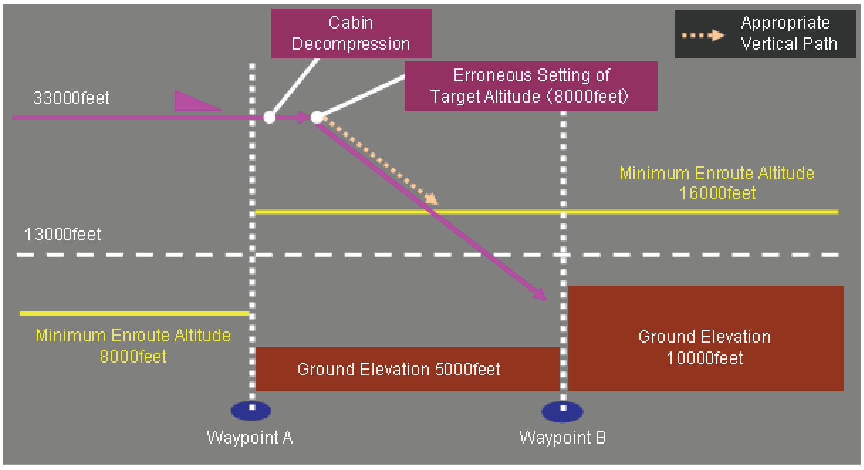

Fig.4. Description of Simulation Scenario 1

Table 2. Results of Simulation (Scenario 1)

	Error Detection Time	Cues of Error Detection
EPFD	18 sec. (SD 4.0)	Terrain Informnatiuon of EPFD (9/12) Traditinal Indication of Target Altitude (3/12)
Traditional PFD	36 sec. (SD 10.6)	Traditinal Indication of Tar–get Altitude (12/12)

5 CONCLUSION

In the present study, a method to improve HMI based on analyses of cognitive recourses in a field has been discussed toward actualizing a proactive and preventive improvement method of HMI. A prototype information display for the advanced flight deck called EPFD has been developed based on the proposed method and evaluated through a simulation-based experiment. Although the evaluation of EPFD is still preliminary stage, authors believes that the proposed method has a possibility to contribute a proactive and preventive improvement of HMI.

Further research program is now on the way in which the proposed method is applied also to the Air Traffic Control (ATC) area. Authors believe that resilience in the total aviation system realized by the proposed method will contribute to the enhancement of the safety in the aviation.

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