Human Reliability Analysis of Single-Pilot Operations Based on Improved CREAM Method

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Abstract: In order to effectively predict the human reliability of pilots under single-pilot operations (SPO) to ensure aviation safety, the CREAM method is improved to construct a prediction model of human error probability in line with SPO mode. Based on characteristics of the SPO and intelligent cockpit, the common performance conditions (CPCs) are modified and the weighting factors of cognitive function for improved CPCs are analyzed. In addition, new malfunctions in the intelligent aircraft that may arise are identified. In order to verify the improved CREAM method, a malfunction scenario of engine failure under SPO is designed, and the control mode of human cognitive activities corresponding to calculated results is tactical, which conforms to reality, indicating that the improved CREAM method is reasonable.

Keywords: Human Reliability, Single Pilot Operations, CREAM, Onboard Information Tangible System

Introduction

The trend of cockpit design for civil transport airliners is progressive 'de-personalization', with the pilot's role gradually changing from a "flyer" to a system/cockpit manager (Stanton, Harris, & Starr, 2016). In addition, with the proper development of cockpit technology, SPO can help reduce crew costs for airlines without posing threats to flight safety (Harris, 2007). As a result, many countries have made an attempt to SPO mode. This mode is an important area of airworthiness concern for European Aviation Safety Agency (European Commission, 2017), and the concept and operational architecture are proposed by NASA (Comerford et al., 2013). The onboard information tangible system can replace the workload of the other person when a situation arises that requires only one pilot in cockpit with two crew members, which increases the margin of safety.

In order to approach the SPO mode, it is necessary to improve the automation level of cockpit. One way is setting an onboard information tangible system, which is an intelligent assistant device optimized for information collection and processing. Compared to the traditional electronic flight bag (EFB), this system can automatically sense the contexts by real-time interlinking with the data of aircraft systems, so that it can provide the standard operating procedures and suggestions to the pilots accurately and timely, reducing pilots' time pressure and workload for information searching, and compensating for the lack of situation awareness.

Due to the new functions and potential risks of the next generation of intelligent cockpit, it is necessary to analyze human reliability. Human reliability analysis(HRA) has gone through three stages (He & Huang, 2007), the generation 1 is the static HRA methods based on expert judgment and statistical analysis; the generation 2 is the dynamic human reliability analysis models; and the generation 3 is the dynamic modeling system based on virtual simulation technology, which mainly includes IDAC model(Chang & Mosleh, 2007). THERP, SLIM, and CREAM methods are generally used for HRA in civil aviation. Shi et al.(2023) combined linguistic D-numbers with DANP to quantitatively analyze human errors; Garg, Vinod, and Kant(2023) developed a software application based on CREAM to automate the predictive analysis; Zhang et al.(2022) proposed a ATC human failure probability prediction method based on THERP and CREAM. SLIM often combines Delphi and Analytic Hierarchy Process to identify performance shaping factors and quantitatively calculate them(Liu et al., 2018).

Since the generation 1 method has the flaws of lack of sufficient data and lack of psychological foundation, and the generation 3 method lacks the analytical model of cognitive errors, this paper adopts an improved CREAM method.

Improved CREAM method

Adjustments to CPCs

CREAM is categorized into 9 CPCs to measure the impact of situations on human behavior. Initially it was used for HRA of nuclear power plants, but did not fully applied to the actual situations of civil aviation. Although some scientists have carried out relevant improvements in the field of civil aviation, they primarily focused on air traffic control, mechanics and dual-pilot operation(Zhao et al.,2013; Guo et al., 2021) even no CPC dimension specific to the HRA of SPO.

In this paper, the CPCs are modified according to the actual situations of the new generation of intelligent cockpit and single pilot operation, and each CPC is refined into performance influence factors (PIFs) to clarify the dimensions of judgment.

CPC modifications for SPO. In the SPO, the factor of ' Crew collaboration' should be deleted since only one person was in the cockpit for operations. 'Radiotelephony communication' can be added as a CPC accordingly. In addition, the CREAM method lack on corresponding description of pilots conditions which have a significant impact on the occurrence of accidents or incidents. Then the factor of 'state of pilots' is added, including the pilot's physiological and psychological conditions and the level of knowledge and skills about automation. The level of cockpit intelligence has to be increased due to SPO implement, so the factors related to the cockpit automation and onboard information tangible system should also be considered. Based on analysis above and refer to relevant literature(Ye, Bao, & Wei, 2018; Naidoo, 2008; Chen, 2019; Shang, Yang, & Wang, 2023), the CPCs for SPO included PIFs are constructed as shown in Table 1.

Table 1: CPCs and PIFs included

CPC Name	PIFs included
Adequacy of organization (CPC_1)	① Policies and objectives of the organization;
	② Formulation and coordination of emergency plans;
	③ Supervision and inspection;
	④ Safety culture
Working conditions (CPC_2)	① Weather;
	② Airspace conditions;
	③ Noise and vibration;
	④ Temperature and humidity;
	⑤ Lighting
Adequacy of MMI and onboard information tangible system (CPC_3)	① Overall layout design;
	② Display-Control Layouts;
	③ Manipulating devices and display elements
	④ Information of digital interface;
	⑤ System automation levels;
	⑥ System complexity;
	⑦ System reliability
Availability of procedures/plans (CPC_4)	① Standard operating procedures;
	② Emergency procedures;
Number of simultaneous goals (CPC_5)	① Numbers of targets;
	② Difficulty of tasks
Available time (CPC_6)	① Response time allowed by procedures;
	② Time pressure
State of pilot (CPC_7)	① Personal physical fitness;
	② Fatigue;
	③ Workload;
	④ Emotions;
	⑤ Personal traits;
	⑥ Attention allocation;
	⑦ Levels of trust in automation;
	⑧ Knowledge-based level and skill-based level of automation
Adequacy of training and experience (CPC_8)	① Highest level of license;
	② Total flight hours;
	③ Awareness of regulations;
	④ Contents and depth of training courses
Radiotelephony communication (CPC_9)	① Communication complexity;
	② Standard terminology of radiotelephony;
	③ Pilot's ICAO level;
	④ Availability of radio equipment;
	⑤ Frequency interference

Weighting factor analysis of cognitive functions

Since the new CPCs are identified for SPO in this paper, the weighting factors in the original CREAM method can no longer be used, so the basic relationship between the added CPCs and the four categories of cognitive functions should be reanalyzed, and the influence levels can be quantified into corresponding weighting factors. CPC_3, CPC_7 and CPC_9 are analyzed to classify the degree of their influence on cognitive functions as strong, medium, or weak. The impact ratings are shown in Table 2.

Table 2: Couplings between CPCs and cognitive processes

CPC	Cognitive function			
	Observation	Interpretation	Planning	Execution
CPC_3	strong	strong	medium	medium
CPC_7	medium	medium	strong	strong
CPC_9	medium	weak	weak	strong

The rules for quantifying weighting factors according to influence levels are as follows: firstly, the influence of ‘weak’ is ignored, the weighting factor is set as 1 since no correction is made to the final probability of human errors; secondly, the weighting factor is assigned as 1 when the evaluation level is ‘not significant’ since there are different levels of CPC; when the evaluation level is ‘improved’, it means that it has a reduced effect on the probability of errors so that ‘medium’ is assigned as 0.8, meanwhile ‘strong’ is assigned as 0.5. When the evaluation level is ‘reduced’, it means that there is an improved effect on the probability of errors, so ‘medium’ is assigned as 2.0 and ‘strong’ is assigned as 5.0.

Recognition of cognitive function failures

CREAM categorizes human cognitive functions into four categories: observation, interpretation, planning and execution. Each category has a number of potential failures, with a total of 13 failure modes. However, the new generation of intelligent cockpit has a higher level of automation, which may generate some new potential failures: (1) Incomplete or unclear information perception: there are many resources of information input in intelligent cockpit that pilots do not perceive all the information or perceive irrelevant information; (2) Misinterpretation of information: pilots misunderstand the information provided by onboard information tangible system; (3) Interpretation bias: pilots can't understand complex automation systems or lack relevant experience, resulting in an inability to judge the current situation and a biased understanding of the situation; (4) Decision-making conflicts: when the operation provided by onboard information tangible system are inconsistent with pilot's decision, it leads to confusion in the decision-making process; (5) Insufficient trust: pilots ignore assistant information and blindly carry out operations they thought be feasible when they don't trust automation. (6) Perception and execution failures due to overreliance on automation: pilots' overreliance on onboard information tangible system may lead to over focus on the system but ignore actual situations that cause the degradation of pilots’ flight control skills.

Since SPO has not yet been put into use on a wide scale, it is difficult to obtain sufficient data on accidents or incidents, this paper tried to identify potential failures that may arise and then calculates probability of human errors with the reference of original nominal values.

Analysis of engine failure experiment

Description of tasks and HRA event tree construction

The experiment of engine failure under SPO was carried out on the simulator, and the process of experiment was summarized as follows: identify engine failure, perform Electronic Centralized Aircraft Monitoring (ECAM) actions, then according to altitude, airspeed and other parameters, pilot could consider engine relight in flight procedures. At last, the engine could be successfully relighted and the affected systems returned to normal.

Referring to the idea of utilizing HRA event tree for event analysis and qualitative evaluation of human reliability in THERP, the event tree for engine failure is constructed. If pilot in SPO fails to determine to adopt the relight procedure or is unfamiliar with procedures, onboard information tangible system can automatically detect the scenario and display recommendations. The operating procedures displayed by the system are used as remedial measures and corresponding branches should be added to the tree. Based on this, the HRA event tree constructed is shown in Figure 1.

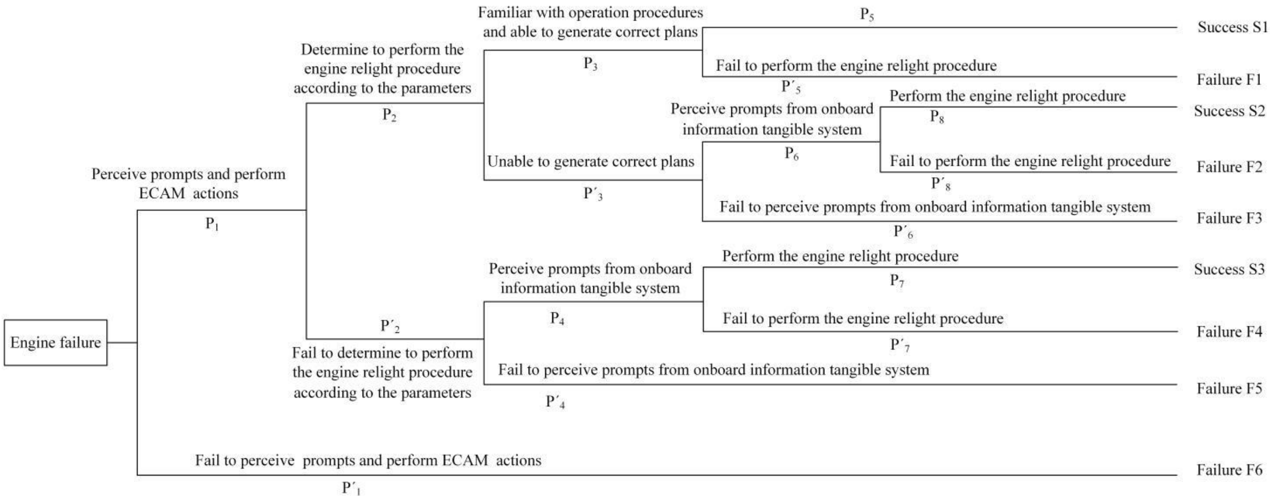

Figure 1. HRA event tree of engine failure

Calculation of human error probability

It is obvious that the failure paths in the event tree for engine failure are F1, F2, F3, F4, F5 and F6. Potential cognitive function failures are analyzed in order to obtain the basic failure probability CFP_0, and the weighting factors are obtained by evaluating the level of CPCs and the dependency rules. The final failure probability is $CFP_i = CFP_0 \times \text{total weighting factors}$, and the probability of the corresponding sub-event is calculated as: $P_{F1} = 1.511 \times 10^{-3}$, $P_{F2} = 7.514 \times 10^{-7}$, $P_{F3} = 2.821 \times 10^{-6}$, $P_{F4} = 1.409 \times 10^{-7}$, $P_{F5} = 9.174 \times 10^{-5}$, $P_{F6} = 8.807 \times 10^{-6}$, so the human error probability is:

$$P = \sum_{i=1}^{6} P_{Fi} = 1.615 \times 10^{-3}$$

According to the relationship between the control mode and the range of errors probability, the control mode in this task is tactical, in which pilots' performance follows known rules. However, the thoroughness of plan is limited by the amount of information obtained from cockpit and is difficult to be perfect (He et al., 2007), which is in line with the actual situation indicating the method is feasible.

Conclusion

To perform HRA for SPO, this paper improves the CREAM method and applies it to analyze the experiments of engine failure. The conclusions are as follows:

（1）CPCs are add related to radiotelephony communication, personnel conditions, automation levels and onboard information tangible system, quantified their influence levels on cognitive functions as weighting factors.

（2）New potential failures such as incomplete information perception, misinterpretation of information, lack of trust, and over-reliance are identified for intelligent cockpit in SPO.

（3）Conduct the engine failure experiment for SPO to validate the improved CREAM method, set the specific steps of HRA. The calculation result conforms close to reality, indicating the method is feasible.

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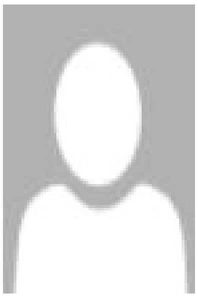
Biography



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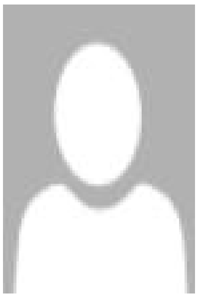

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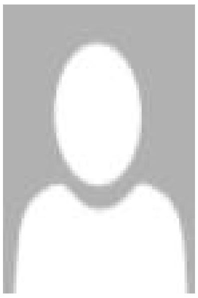

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