Pilot Performance Models

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Abstract. Pilot as the controller of the aircraft whose performance is key for aviation safety. This paper investigated three main pilot models at present. The models all can solve the problems they are expected to well, but there is no model that has integrated architecture for pilot information processed. According to the characters of pilot executing tasks, the paper built the architecture of "pilot in the loop" model. The model is dynamic and has the ability to simulate the interaction of human-machine, and can also reflect the micro mechanism and macro behavior of pilots. The difficulties of modeling have been analyzed and the methods to solve the problems have also been put forward.

Keywords: pilot modeling, human in the loop, cognitive model, control model, Fitts' law.

1 Introduction

More than two-thirds of all aircraft accidents are attributed to pilot error. Identifying when equipment and procedures do not fully support the operational needs of pilots is critical to reducing error and improving flight safety [1, 2]. And the capabilities, limitations of pilot will be basis of the new flight deck design. But the latent design flaws cannot be discovered in nominal scenarios but in off-nominal scenarios which can induce serious pilot error and flight accidents. The off-nominal scenarios are not so easy to be designed and executed in experiment research and the flight accidents in off-nominal scenarios are always rare. There is not enough data to investigate for the pilot performance research. The researchers have been built many pilot models such as optimal control model, ACT-R, Air-MIDAS and so on to investigate pilot performance both in nominal and off-nominal scenarios [2, 3]. There are pilot control models for flight quality, and cognitive models for the display system design and evaluation and error prediction, and also anthropometry pilot models for flight deck layout design and evaluation. The current models can evaluate design, predict pilot error and discover the latent design flaws, but they are not perfect because of not covering the whole process of flight task by pilot, and they can only find partial key latent design "flaws", or evaluate parts of cockpit design or the model is rough and cannot simulate pilot performance correctly. The model writers' team had built is based on the current model, but aimed at the real and whole pilot flight task process both in nominal and off-nominal scenario such as atrocious weather condition.

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2 Extensive Understanding of Pilot Behavior

Effective pilot models require extensive understanding of the task and the domain environment and the pilot behavior in order to produce valid and meaningful results. Flight task is complicated. The task will be accomplished successfully both by ATC (Airplane Traffic Controller) and pilots. The pilot is the one who receives information and also the one who makes decision and performs. The job is high art needed, which requires the performers to react to the variable environments sensitively and properly. The unique performance of flight task induces special cognitive and operational performance of pilot.

The processes of pilot to execute a typical flight task can be divided into cognitive process and motor process. The cognitive process begins at stimulus produced by the cockpit, and ends up with the decision made. Before he can manipulate an airplane the pilot is expected to learn lots of declarative knowledge, and also should have the capability to transform declarative knowledge to procedure knowledge as quickly and precisely as he can. During the task there is huge information such as flight path, airplane state, and also the environment out the window and so on for him to choose and he is expected to make decisions from the cognitive quickly and effectively. This is cognitive process. The motor process begins right after cognitive process, and ends up with an action over. When the decision is checked out, pilot is expected to do actions effectively following the instruction. During the whole task, pilot is expected to follow the pilot operation procedure strictly, and there is no chance for pilot to make mistake even a tiny one.

From the process we can learn that pilot works under high workload and pressure, the cognitive process is pivotal for the success of whole task, but its success cannot assure the ultimate success. The current model can simulate the cognitive process well or see the human as a function. None of the present model can simulate the whole process well. But for the pilot modeling, every specific character should be simulated correctly.

3 Overview of Typical Pilot Models

The human pilot behavior during flight tasks is a fundamental component of the overall aircraft control loop. From an initial review of past efforts in pilot behavior modeling, they can be classified as two different kind pilot performance models, which are pilot control models and cognitive models. Each kind model will be described in model development, and significant findings for the aviation community.

3.1 Control Model [4, 5, 6]

Over the years, there has been a large amount of research in the input-output representation of manual control, with significant contributions especially for modeling linear and pseudo-linear tracking tasks. The model based on control theory has been passed through three phases from Transfer-function model, optimal control model to fuzzy control model. A variety of techniques were used based on frequency domain methods, as well as algorithmic time domain methods.

The control model is focused on flight quality concerned with pilot performance, such as PIO (Pilot-Induced- oscillations). The pilot is considered as controller of the plane and the pilot is just a part of transfer function. The model is effective to evaluate flight quality and the affection of pilot for the flight, but from the model we cannot analysis the detail behaviors of pilot and the specific influence can also not be acquired.

Control model is always built based on control theory. And the general model is expressed as transfer function G(s).

The control model is maturity enough for users to predict system performance and initial optimization. But the essential limitation is that the model cannot consider the pilot performance precisely which is always considered as a part of transfer function and the particular performance of pilot in nominal or off-nominal cannot be concluded. The limitation leads to the simulation results not so accurate and reduces the results reliability.

3.2 Cognitive Model

Cognitive model focuses on how human reacts on the stimulus, especially on the process of thinking and then how to decide. The theory of cognitive model is information processing which generally divides the cognitive process into three parts which is perception, thinking and decision and response [7]. Thinking and decision is the hot point and also the most important for all research. There are also various models especially for this process. And attention acts on the whole process.

The cognitive models were mainly developed by NASA in 2001[1, 8] and also the beginning of the model for engineering. The primary goal of the project was to develop and extend human modeling capabilities while gaining knowledge regarding aviation operations and supporting emerging capabilities and technologies that increase aviation safety. The two aviation domain problems addressed by the models are: Airport surface (taxi) operations and Synthetic vision system (SVS) operations. There are five models:

1. Adaptive Control of Thought-Rational (ACT-R);
2. Improved Performance Research Integration Tool/ACT-R hybrid (IMPRINT/ACT-R);
3. Air Man–machine Integration Design and Analysis System (Air MIDAS);
4. Distributed Operator Model Architecture (D-OMAR); and
5. Attention-Situation Awareness (A-SA).

The usefulness of five cognitive models to the design and evaluation of new technology is determined to a significant extent by the core capabilities – visual attention allocation, workload, crew interactions, procedures, situation awareness, and error prediction. There are two significant functions which are error prediction and mitigation and display design and information allocation. But the model framework had not covered the whole process, which induced that the model could not predict pilot error except cognitive error and evaluate manipulate and control system.

However, the five cognitive models indicate that the art of human performance models has advanced to a level of maturity. They are now considered important tools in the aircraft design, analysis and evaluation.

3.3 Anthropometry Pilot Models

Anthropometry models conclude kinetics model, kinematics model and biodynamic model and so on. For the engineering use, a perfect anthropometry model always considers the kinetics, kinematics and some biodynamic of manikin.

The current anthropometry model is very well-developed and there are various softwares containing these models for system design and evaluation, especially for ergonomics design and evaluation. CATIA/DELMIA, JACK, RAMSIS all are the typical manikin models and widely used in aviation. And the Chinese pilot anthropometry data can be imported into the software to build the Chinese pilot manikin model. The anthropometry data of Chinese pilot comes from GJB 4856-2003 (Human dimensions of Chinese male pilot population).

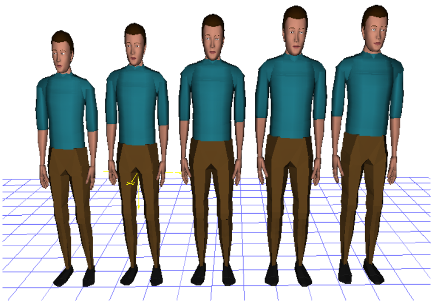

Fig. 1. Chinese pilot model in JACK

The anthropetry model of pilot has been widely used in aircraft design, analysis and evaluation. But the instruction is limited in the system layout or the operation analysis. What the objects think and what they would do if the scene changed is not considered in the anthropometry models and so is the dynamic simulation and evaluation.

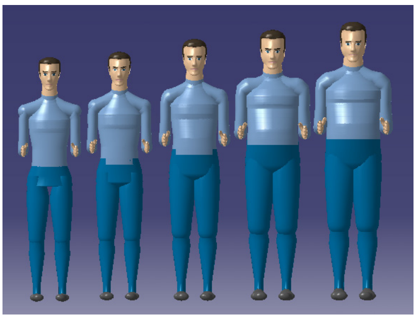

Fig. 2. Chinese pilot model in CATIA

3.4 Fitts' Law

The operation of buttons on panel in the cockpit is defined as "target-pointing" operation, and Fitts' law deprived from information theory is most used to investigate accuracy and time of the operation [10]. There are various formats of Fitts' law. Many people have done some amazing job to perfect the law since 1954. The work concludes different movement types, different operators, and different equipments and so on.

The initial format of Fitts' law [11] is:

$$MT = a + b \cdot ID \tag{1}$$

Where a, b is the experienced parameter of the particular task, and ID is index of difficulty and is the function of the target width (W in the following expression), and distance from the initial position (A in the following expression).

$$ID = \log_2 \left(\frac{2A}{W}\right) \tag{2}$$

The most widely used expression is as follows:

$$T = a + b \log_2 (A/W + 1) \tag{3}$$

Although Fitts' law is widely used for the interface design and evaluation, it just considers the last part of the whole operation task, and the whole process of thinking is just omitted. Maybe we can also say the whole process of thinking is represented by a macro parameter ID (index of difficulty). This is not so strict for research.

4 Integrated Pilot Performance Model

The pilot model has already be used in design and evaluation, but from an initial review of past efforts in modeling, it was recognized that no single modeling architecture or framework had the scope to address the full range of interacting and competing factors driving pilot actions in dynamic, complex environments [1]. The research team has built an integrated pilot performance model which can compensate the architecture flaws of other models and expand multiple modeling efforts. The architecture of the model is shown in figure 3.

There are three main parts: simulation environment, pilot model and ground guide. Simulation environment includes world environment, airplane itself and the flight dynamics model to support flight; Pilot performance model is based on the process pilot executes flight task which roughly divided into four parts, and during every process the attention will join in and affect the actions, while ground guide part receives information from the environment and then guides pilot.

All the three parts constitute the whole flight process, and pilot is the centre obviously. The pilot performance model is built based on the process pilot executes tasks. For the model, we consider the motor module has equal importance to the perception module which is different from the previous models. The two aspects of previous models are apt to imbalance. Motor is only a factor for the whole model, and most of them had just used one-dimension Fitts' Law to simulate the human operation. The inadequate consideration of motor induces the model is not as accurate as it was. The model based on the task process takes "operation" as important as it is. The builders have been extending Fitts' Law to three-dimension to simulate human real operation and predict operation error both in nominal and off -nominal scenarios. Not just for the motor performance and the other performances of pilot would be investigated in the new-built model. To enable model development, information would be collected from task analyses and objective data and subjective ratings in the closed loop both in nominal and off -nominal scenarios.

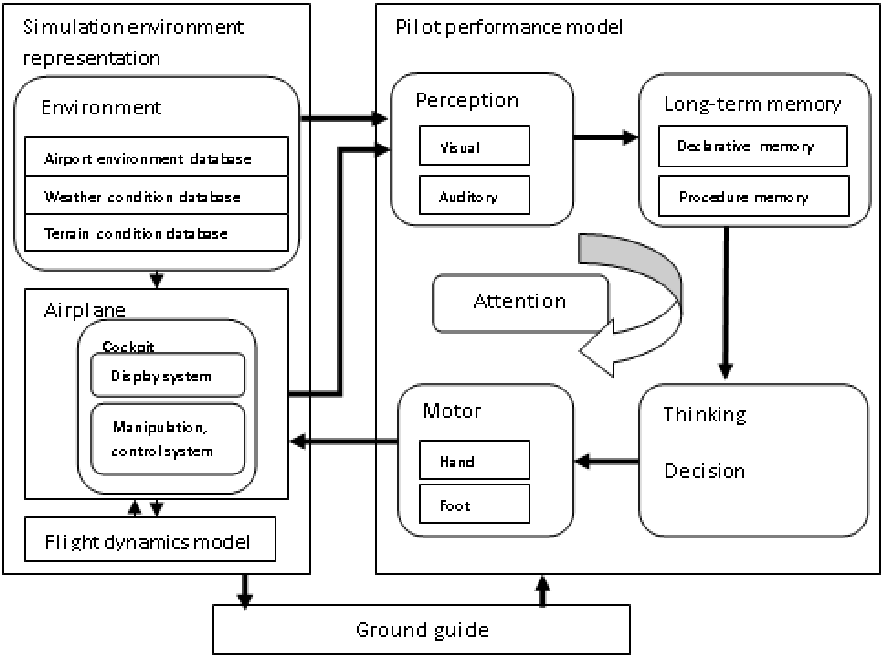

Fig. 3. Architecture of integrated pilot performance model

5 Conclusion and Discussion

Each pilot model has its own advantages and disadvantages. But each model has extended its capabilities significantly to answer important aviation domain questions and has shown considerable efforts for the human performance model development. As mentioned before, however, the integrated pilot performance model can simulate pilots more roundly and accurately. There are two major improvements of the new model. First the model can be used to simulate pilot operation easily and precisely. The model built based on the whole task and the operation part is put the same as the cognition. The three-dimension Fitts' Law would be used to model pilot operation results, and the design "flaws" induced by operate equipment would be found. And the error probability model would be used to predict human errors, especially the error induced by operation. After all, since we consider operation as a big part of the model, the problems about operation would be solved accordingly. For example, by the model we have the ability to check if the procedure is reasonable.

However, we still have huge work to do to perfect the model. The motor module is not only a three-dimension Fitts' Law model, the module should be effective in both nominal and off-nominal scenarios and also have the ability to predict errors caused by operations. And the off-nominal scenarios are not so easy to be designed and executed in experiment research and the flight accidents in off-nominal scenarios are always rare. There is not enough data to investigate for the pilot performance research. How to get the data to support the model is also a big problem.

Another problem is how to validate model. The appropriate validate method is pivotal.

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