Predicating the Safety of Airport Approaches Using a Cognitive Pilot Model

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Abstract. This paper introduces a new cognitive flight operator model (CFOM) that has been developed for predicting the safety of airport approaches. The creation of the CFOM is based on the frequency and percentage of accident associated with Human Factors Analysis and Classification System (HFACS) causal categories by types of operation. Operator capacity limitation, decision heuristics and action error mechanisms are incorporated into the architecture of CFOM to produce the behavior errors. This cognitive model integrated with an environment model consisting of a model of airplane, aircraft dynamics, and flight environment forms Man-Machine-Environment Safety Analysis System (MME-SAS) that canbe used to investigate the cause of human errors and aircraft accident.

Keywords: Human Performance Modeling, Decision Heuristic, Rule Chunk Model.

1 Introduction

Within complex aviation systems around 60% to 80% of accidents and safety compromising incidents are attributable, at least in part, to human error [1-2]. Developing an analysis method or models capable of representing the many multiple potential factors and those factors interacting within the complex and dynamics environment is an effective way to investigate and predict the cause of the accident.

There are many different methods to understand the cause of the pilot errors and accident. The traditional method is accident investigation procedure including the experts review the accident chain that is time consuming and the result is often affected by the background of the expert. Another alternative to predict pilot error is Human Error Identification (HEI) approach [3], the use of this structured method to predict the errors that are likely to be made by operators during task performance. The flaw of this method is that the participants with no experience of HEI method or piloting in general is a significant limitation and is prone to blind spots. Controlled human in the loop (HITL) experimentation provides excellent means for collecting relatively real data, while the HITL simulation are significantly limited in their ability to reproduce a large number scenarios and high cost of HITL simulation.

To remedy the limitation of the methods discussed previously, computational cognitive models of human behavior is developed that can be used to predict the pilot

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error and safety analysis [4]. The computational cognitive models should allow us examine the underlying cause of errors (e.g., system design, operating procedure and pilot capability), providing a tool to investigate error chain and assist redesign the procedure or system to mitigate errors. Several computational cognitive models have been developed to model the pilot error in commercial aviation region [4-5]. However, few models are able to simulate the pilot errors in the approach scenario.

The pilot cognitive model presented in this paper is a combination of a skill- and rule- based model. The skill-based model provides unconscious action such path tracking and stabilization. The part of rule-based model concerns the procedural behavior of the pilot. Both parts integrated together with environment model such as aircraft kinematics and dynamic constraints, aircraft configuration forms a complex dynamic Man-Machine-Environment Safety Analysis System (MME-SAS) to evaluate and predict the pilot error to analysis the safety of the system design and procedure.

2 Basic Principles of Method to Model the Pilot for an ILS Approach

This section describes the basic principles of method to model the pilot for an Instrument Landing System (ILS) Approach; Namely, the assumptions and choices that have been incorporated in this research, and what is not adopted as the scope of this research.

2.1 Flight Task

The selected task occurs in the most important part of every flight: the approach. The approach phase typically consists three segments, including initial approach, intermediate approach and final approach, in which the flight crew performs different actions according to the Standard Operating Procedures (SOPs). As the intermediate and final approaches represent the most complicated and error prone phases during approach, the research only takes into account the phase shown in Fig. 1.

Instrument landing system (ILS) is highly accurate facility by which the airplane is navigated to the runway. ILS consists of three of transmitters –the localizer, the glide slope, and marker beacons [6]. The localizer provides lateral guidance and glide slope provides vertical guidance, and the distance measurement relative to the runway is given by Marker beacons. A precision approach is an approach descent procedure in which navigation equipment aligned with a runway where the glide slope information is given. The crew can execute a precision approach when all ILS systems are available and a clearance is announced by the ATC. In [6], a standard approach ILS procedure is illustrated. The following three parts are used:

- If the heading of the aircraft is aligned with the runway heading, the pilot changes the aircraft configuration, such as deploying the flap according speed limit, using the speed brake to decelerate the aircraft. When the glide slope is intercepted, the crew extends the gear. While in the approach, the flight path angel is nearly 3° .

- The main activity of the pilot is maintaining the configured aircraft on the glide slope and the localizer with desired speed. While slight undershooting of desired speed is acceptable. In the final approach, the crew monitors the systems, the attitude and flight path of aircraft, and control the aircraft by the difference between the state of aircraft and expectation.
- At the end of approach, landing maneuver is performed. The pilot initializes the flare on a prescribed altitude, controls the thrust lever in the idle position and makes a pitch up command until the main gear touch down the runway.

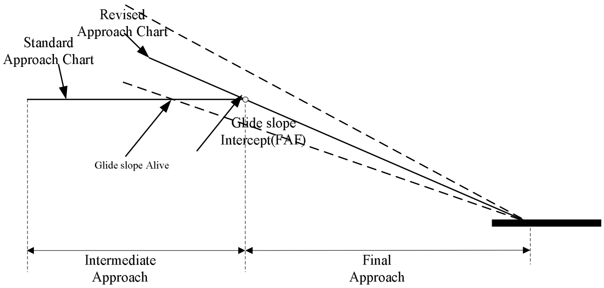

Fig. 1. Revised Approach Chart

As the aim of this work is to develop a cognitive pilot model for ILS approach which is a high precision task. To simplify the modeling, a revised approach chart (see Fig.1) is used in computer simulation. In this chart, only motion in vertical plane was considered, which means the initial heading of aircraft is align with the heading of runway, and there is no crosswind to affect the lateral motion of aircraft. Based on this assumption, the pilot need not control the aileron and rudder surface.

The flare is simulated in HITL simulation while not modeled in the computer simulation because of the optical perception is an important information source during flare, the research only focuses the first two parts of approach.

2.2 Factors Influencing the Safety of Approach

There are so many factors that influence the safety of the approach, the direct factors including meteorological conditions, aircraft, pilot and procedures etc [7]. It is impossible to investigate all the factors which may lead to a pilot error and aviation accidents. In [8], the majority of accident causal factors are classified using the human factors analysis and classification system (HFACS) that is a theoretically based tool used for investigating and analyzing human error associated with accidents and incidents. The unsafe acts of crew are mainly due to aircrew and their environment. For the environment conditions, the casual factors typically associated with aspects of physically environment such as weather and lighting, as for aviation crew, the majority of aviation accidents causal factors are found at unsafe act level, over half of accidents are related to at least one skill-based error and over a third with decision error.

As so many endeavors has been invested to explore the environment constrains using human sensory, biomechanical and control-theoretic pilot model, it is imperative to investigate the aspects of pilot which induces to errors and failure of pilot vehicle system. With respect to the pilot performance modeling, it is tremendous complexity to include all aspects of pilot whereas the pilot performs perception, decision and motor control, often in very tight sequence [9]. In this research, a hypothesis is made that the critical aspects of pilot which affects the safety of aviation will only be modeled, that is capacity limitation, decision and action strategy.

2.3 Framework of Pilot Model

The approach to integrated pilot modeling in this research centers on the development of pilot model in the framework of a cognitive architecture. The cognitive architecture is a general framework to specify the computational behavioral models of human cognitive performance [10]. This architecture can be used to simulate abilities of pilot constrains such as memory decay, limited motor action and foveal versus peripheral visual encoding; and abilities such as learning, decision, perception and motor performance. As such, by abiding all the limitation of pilot model, the cognitive architecture makes the pilot model developed in this framework valid. The pilot model developed in this research is based on this framework. Detail information about the pilot architecture in illustrated in following part

3 Architecture of MME-SAS

The MME-SAS model is framework of models that can be used to evaluate and predict the pilot performance. Pilot cognitive model integrated with environment model (flight dynamic model, automation, weather condition) form a closed loop in which the output of one part servers as the input to another part. The architecture of MME-SAS is illustrated in Figure.2.

3.1 Overview of MME-SAS

The CFOM is a framework of model that predicts human performance. Current aircraft status information indicated on Primary Flight Display (PFD), Navigation Display (ND), and Engine Indication and Crew Alerting System (EICAS) are perceived to determine whether decision must be made. The perceived incoming information through situation awareness process including filtering, comprehension, retrieval and grouping, and ultimately forming situation assessment on the incoming information, this research assumes that incoming information is not distorted and filtered and the situation awareness is sufficient to detect the abnormal event. Following the information pre-processing process, decisions are made based on the result of situation awareness. The output of decision is a stream of actions at "know-how" level, these actions server as the input to environment in which the operators act. The environment dynamically responds to the CFOM's output and feedbacks the system state.

Cognitive activities are influenced by abilities and constraints of operator.

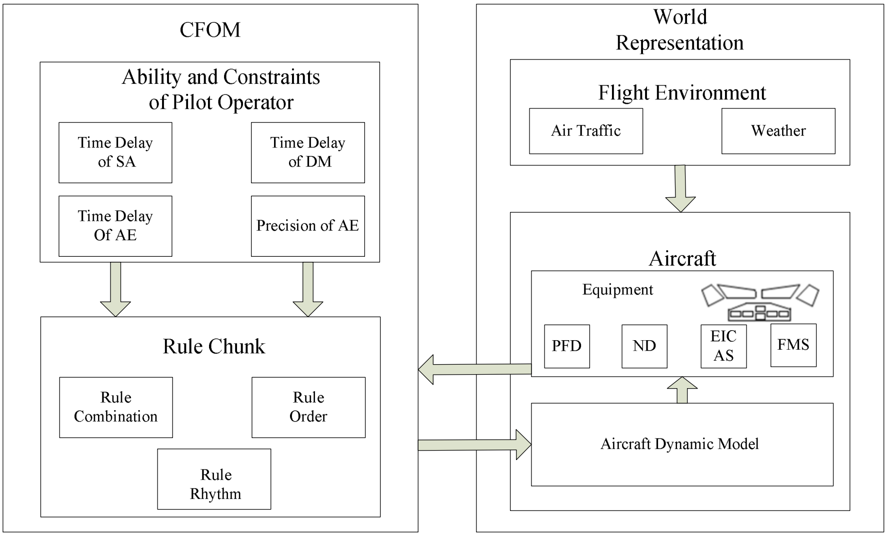

Fig. 2. Architecture of MME-SAS

3.2 Ability and Constraints of Human System

In aircraft system, operator capabilities have great effects on the handling qualities of aircraft. The abilities and constraints of CFOM are expressed by time delay of cognitive activities and control precision. Time delay of operator is divided into time delay for situation awareness, decision making and action execution. Different probability distribution is used to represent the difference and randomness of cognitive characteristic and. For example, the different situation awareness time specifies the time that the operator needs to accomplish the assessment of system state. Sufficient situation awareness needs enough time that may have effect on the safety of system. Control precision reflects the skill proficiency of different operator, meanwhile, the distribution of control strategies provide the error mechanism for slips. Novice and veteran operator can be specified by different control precision.

3.3 Rule Chunk Model

Reason [2] distinguished three categories on human behavior: skill-based, rule-based and knowledge-based. Skill-based behavior assigns stimuli-response in an automatic mode that are routinely practiced (e.g., when the aircraft pitch angle is small than desired angel, the pilot will pull the side lever). Rule based behaviors determine the responses for situations that have been encountered before, such as through training in simulation or experience, are combination of conscious and unconscious process (e.g., routine landing checklist and takeoffs). Lastly, the knowledge-based behavior requires inference to determine a response when other methods have been proven unsuccessful, often the broader and profound of the pilot's knowledge, the more likely a good solution the pilot will make.

The behavior of the pilot model developed in this research is rule-based and skill-based. Namely, the rule-based behavior can model the strategies such as rules, choices and procedures employed by the crew; the skill-based level represents visual scan pattern, situation awareness, and motor action of pilot.

In the CFOM decision phase, using If [certain set of conditions meets] Then [perform one or more action] pairs reflect the experience and knowledge of pilot. Each rule is essentially a condition-action rule that generates specified actions when the condition is satisfied.

The rule-based model includes a rule chunks, using If [certain set of conditions meets] Then [perform one or more action] pairs reflect the experience and knowledge of pilot. Decision strategies specified by rules are different with individual pilot from different countries and airline. It is reasonable to comprise all the possible rules that pilot will used in dynamics environment. However, it is difficult to get the pilot control rule. In this research, several basic pilot skill rules concluding from Flight Crew Training Manual (FCTM) arranged with different order, rhythm and frequency (equation 1, 2, 3) to generate a rule chunk that reveals the different tactics.

$$R_1R_2\cdots R_i\cdots R_j\cdots R_{m-1}R_m \xrightarrow{order} R_1R_2\cdots R_j\cdots R_i\cdots R_{m-1}R_m \tag{1}$$

$$R_1R_2\cdots R_i\cdots R_j\cdots R_{m-1}R_m \xrightarrow{rhythm} R_1R_2\cdots R_i\cdots R_j\cdots R_i\cdots R_j\cdots R_{m-1}R_m \tag{2}$$

$$R_1R_2\cdots R_i\cdots R_j\cdots R_{m-1}R_m \xrightarrow{order} R_1R_2\cdots R_iR_i\cdots R_jR_j\cdots R_{m-1}R_m \tag{3}$$

During action execution phase, operator will output a control on throttle, flap lever, throttle lever,speed brake lever, landing gear lever or other control equipment if any decisions are made to change the aircraft status. Denoting δ_e , δ_t , δ_s , δ_l , δ_f as elevator deflection, throttle position, speed brake position, landing gear status and flap deflection. T_{SA} , T_{MD} , T_{AC} denote situation awareness, decision making and control time delay respectively. Note that control precision provides the pilot control error that exists on all action or motor control. The output of control can be expressed as below:

$$\delta_a = \left[\delta_{a0} + P_{\delta_e} \right] \tag{4}$$

δ_a and δ_{a0} are aft-control and pre-control value, P_{δ_e} is control increments.[] is an operator for saturation constraint of controls.

3.4 Representation of External Environment

The external environment is the environment in which the flight crew, in aviation domain, the external environment represents the aircraft's handling quality, performance characteristics, flight deck displays and instrumentation, and the atmosphere and air traffic. The fidelity of external environment mostly is a difficult decision point, a high-fidelity environment can closely represent the response of pilot action and provide the pilot more accurate and real flight information. On the other hand, a high-fidelity of external environment can be time consuming and expensive. In this research, a simple aircraft kinematic equation is constructed to simulate the continuous aircraft status by referring[11], the simplification incorporates the most significant impact on action/response feedback mechanism.

4 Results of Computer of Simulation

MME-SAS is simulated based on the basic principles and assumptions, as explained in the previous section. The mission in the simulation can be view as the management of aircraft's attitude to maintain desired height and speed during approach and landing phase. The mission begins with an initial point where the aircraft status is balanced and ends with touchdown point on the runway, pilot try to keep the path angle with glide slope equal to -1:29.

In order to simplify the approach process, the simulated virtual pilot should conform to a revised approach chart that prescribes the pilot action. Although the MME-SAS should work for any aircraft type, however, a Boeing 747 aircraft is used in the simulation. The aircraft model is modeled based B747-100 documentation [12], so the SOPs that are modeled in computer simulation are based on the SOPs that are for B747.

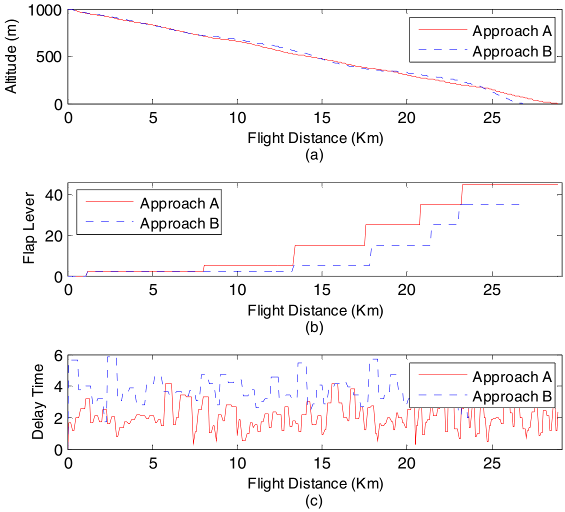

Fig. 3. Results of two different approaches

Two different approaches are simulated to reveal the linkage between operator capabilities with the flight safety. The results are illustrated in Fig.3.Obviously the touchdown points in approach A and approach B are (289221m, 0, 0) and (268517m, 0, 0) respectively, we can conclude that the approach A is more successful than approach B with respect to flight trajectory. Fig.3(b) shows that for approach B, the flaps is not fully deployed that only 30°is used by the pilot. The reason for this is showed by Fig.3(c) that the pilot time for B is larger than for A, meaning that the time delay affect the pilot performance greatly. It can be concluded that the time delay of approach B showed in Fig.3(c) cannot be used to design the aircraft automation system.

5 Conclusion

In this paper, a computational model of pilot behavior combined with aircraft and flight environment model is built in this paper forms a MME-SAS that links the human factors and handing quality of aircraft with the performance of flight. Computer simulation results show that MME-SAS can be used to investigate the cause of pilot error and accident.

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References

1. Shappell, S., Wiegmann, D.: U.S. naval aviation mishaps 1977-92: Differences between single- and dual-piloted aircraft. Aviation, Space, and Environmental Medicine 67, 65–69 (2006)
2. Reason, J.: Human error. Cambridge University Press, New York (1990)
3. Shorrock, S.T., Kirwan, B.: Development and application of a human error identification tool for air traffic control. Applied Ergonomics 33, 319–336 (2002)
4. Gray, W.D.: Integrated models of cognitive systems. Oxford University Press, New York (2007)
5. Mark, R., Anderson, C.C., Greg, D.: Flight test maneuver design using a skill- and rule-based pilot model. In: IEEE International Conference on Intelligent Systems, pp. 2682–2687 (1995)
6. Nolan, M.: Fundamentals of Air Traffic Control. Wadsworth Publishing Company, Belmont (1994)
7. Monique, H., Theo, V.H., Max, M.: Flight Mechanical Evaluation of Approaches. Journal of Aircraft 48(3) (May-June 2011)
8. Scott, S., Cristy, D., Kali, H., Carla, H., Albert, B., Douglas, A.W.: Human error and commercial aviation accidents: Analysis using the human factors analysis and classification system. The Journal of the Human Factors and Ergonomics Society, 49–227 (2007)
9. Byrne, M.D., Pew, R.W.: A History and Primer of Human Performance Modeling. Reviews of Human Factors and Ergonomics 5, 225 (2009)
10. Meyer, D.E., Kieras, D.E.: A computational theory of executive cognitive processes and multiple-task performance: Part1. Basic mechanisms. Basic mechanisms. Psychological Review 104, 3–65 (1997)
11. Zipfel, P.H.: Modeling and Simulation of Aerospace Vehicle Dynamics. American Institute of Aeronautics and Astronautics, Inc., Reston (2000)
12. Hanke, R.C., Nordwall, D.R.: The Simulation of a Jambo Jet Transport Aircraft. Modeling Data, vol. II, NASA Rept. D6-30643, 1–647 (September 1970)