Human Factors Modeling Schemes for Pilot-Aircraft System: A Complex System Approach*

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Abstract. The human factor is becoming a main topic in modeling and simulation, especially in airline safety as more aviation accidents are classified as pilot (human) errors. Traditional modeling schemes treat pilots and aircraft individually, assuming the other as given. However, to define a system-level architecture for the safety analysis, it is advantageous to expand the system boundary to include both pilots and aircraft as a coupled entity. In this paper, we propose a framework for pilot-aircraft system modeling scheme from a complex systems point of view. Key pilot factors are identified and quantified, and complex relationships and interaction among these factors are incorporated into usually well-modeled aircraft system. We also introduce a fast-time simulation model of man-aircraft-environment complex system with the human strategy model as its core to generate large sample sizes of flight data for this modeling purpose. The given results not only provide a proactive approach to the research of flying safety, it can also be applied to other complex dynamic systems.

Keywords: human factors, complex dynamic systems, coupled modeling, distributed information and control.

1 Introduction

With the increasing advancement and complexity of technological systems that operate in dynamically changing environments and require human supervision or a human operator, the relative share of human errors is increasing across all modern applications, especially in the air transportation industry. Although maintenance, manufacturing design flaws, and operational deficiencies other than those of the pilot are typically cited as cause factors, the major cause of all aviation accidents is pilot-error. Some studies suggest that approximately 70% of aviation accidents are classified as pilot-error[1], while others indicate that all accidents have some form of human error attached to their cause[2]. Table 1[3] shows the major airline crashes in the U.S. from 1989-1999. This may be unfair to pilots because accidents are often a result of a chain of events in which the pilot is the last link in the chain. But, often the pilot's

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Table 1. Major US airline crashes: 1989-1999

Date	Carrier	Location	Fatalities (On Board)	Cause category[a]
07/19/89	United	Sioux City, IA	111 (298)	Maintenance
01/25/90	Avianca	Cove Neck, NY	73 (158)	Pilot-error
02/01/91	Skywest	Los Angeles, CA	12 (12) + 22[b]	Miscellaneous, other
02/01/91	USAir	Los Angeles, CA	22 (89) + 12[b]	Miscellaneous, other
03/03/91	United	Colorado Springs, CO	25 (25)	Undetermined
03/22/92	USAir	La Guardia APT, NY	27 (51)	Pilot-error
07/02/94	USAir	Charlotte, NC	37 (57)	Pilot-error
09/08/94	USAir	Aliquippa, PA	132 (132)	Undetermined
10/31/94	American Eagle	Roselawn, IN	68 (68)	Pilot-error
05/11/96	ValuJet	Everglades, FL	110 (110)	Not given
07/17/96	TWA	Long Island, NY	230 (230)	Not given
01/09/97	Comair/Delta Connection	Monroe, MI	29 (29)	Not given

judgment in handing emergency situations is the final deciding factor as to whether the event will result in an accident. Reliable model of pilot-aircraft is therefore essential for aviation safety.

Conventional approaches focus on analyzing four major classifications of factors that have traditionally associated with pilot-error, that is, environmental factors, aircraft factors, airline-specific factors, and pilot-specific factors. Researchers tend to concentrate on only one category when designing their safety study. Our aim is to develop a model incorporating two of them, that is, the pilot-aircraft system. The incorporation of the human factor into the aircraft models is very difficult. The behavior of the pilot is influenced by a big number of environmental, physiological, and other kind of parameters that are difficult to measure. Furthermore, other human factors, like pilot-induced delays, varied control precisions, and the capability limitations and constraints of human behaviors, can all have a significant effect on the flying qualities of the aircraft. Conventional human behavior models, though investigated broadly, could not be rich enough in modeling pilot-aircraft systems as such systems are complex in a sense that they exhibit new properties, not easily deducible or found from properties of their individual parts. Due to interactions of different parts in complex systems between themselves and with dynamically changing environment, coupled effects and phenomena are becoming increasingly important in studying such systems.

In this paper, we study how human factors can be effectively coupled into the modeling and control of the pilot-aircraft system from a complex system point of view. From analytical point of view, such systems interact with their environments, and due to a degree of uncertainty in this dynamic interaction, many associated problems require the development of approaches with a substantial reduction in a priori information required for their applications. Such situations are typical for most complex systems. In this case, rich data must be gathered for accurate approximation, considering all exogenous perturbations and environmental data. Therefore, a fast-time simulation model of man-aircraft-environment complex system with the human strategy model as its core is constructed to generate large sample sizes of flight data for this modeling purpose. It is worth mentioning that such data, which is from distributed information resources, though remain as a challenge for humans, can be leveraged for collaboration and control strategies for further research.

The presented coupled modeling and control schemes in this paper aim to reduce design cycle time, support quantitative predictions of human-system effectiveness, and improve the design of crew operating procedures. It is also noteworthy that our new approach, that takes into account the more complex relationships among relevant factors, not only provide a proactive approach to the research of flying qualities, it can also be applied to other complex dynamic systems.

2 Complex Systems Approach

Various informal descriptions of complex systems have been put forward, and these may give some insight into their properties. One of the defining features of complex systems is that a complex system is one in which there are multiple interactions between many different components. Therefore, complex systems may have certain coupled features, such as:

- Cascading Failures[4]

Due to the strong coupling between components in complex systems, a failure in one or more components can lead to cascading failures which may have catastrophic consequences on the functioning of the system.

- Dynamic network of multiplicity[5][6]

As well as coupling rules, the dynamic network of a complex system is important. Small-world or scale-free networks which have many local interactions and a smaller number of inter-area connections are often employed. Natural complex systems often exhibit such topologies. In the human cortex for example, we see dense local connectivity and a few very long axon projections between regions inside the cortex and to other brain regions.

- Relationships are non-linear

In practical terms, this means a small perturbation may cause a large effect (see butterfly effect), a proportional effect, or even no effect at all. In linear systems, effect is always directly proportional to cause. See nonlinearity.

It is not hard to tell that the pilot-aircraft system in nature is a complex system. Coupling or interaction is the defining feature of this system. Unfortunately, existing theories of such man-involved complex systems may never be reducible to analytical equations, but are more likely to be sets of conceptually simple mechanisms interconnected that produce context-specific dynamics and outcomes. A human strategy model is developed via critical coupling of multiple characteristic patterns to test various flight conditions and to generate flight data with wide representation. This coupled human-aircraft modeling method proposed in this paper provides an algorithmic/numerical approach to establish a unifying framework for decoding the internal dynamics of man-involved complex system and lead forward unifying algorithmic theories of the relations among system complexity, adaptive behavior, and parameter uncertainty.

3 Modeling Schemes

The human factors have been deeply studied by researchers from different disciplines, however most of these models are traditionally very qualitative. Obviously, integrating qualitative models in simulation models could introduce significant criticality in term of confidence band definition, tolerance and model validation. However, theories of man-involved complex systems are difficult if not impossible to be reducible to analytical equations. We here propose a modeling framework which is sets of conceptually simple mechanisms interconnected that produce context-specific dynamics and outcomes. Quantitative results can be obtained from extensive simulation experiment. In fact, to guarantee the reliability of the model, it is necessary to have a very large amount of data that is detailed and/or difficult to measure. Our approach enables such data generation with wide representation.

In order to model such complex system, the first step is to identify key pilot factors. Researches on human factors in aviation have been conducted, and some major aspects of human factors with significant impacts to flight safety are identified[9]. Human factors influencing flight safety include but not limited to:

1) Pilot's control time and control precision;
2) Visual scene of the cockpit and out-of-the-window area;
3) Pilot's workload and workload increment;
4) Pilot's fatigue and fatigue related error;
5) Pilot's prediction on parameter variation;
6) Pilot's situation awareness;
7) Pilot's fast recognition on unacceptable conditions;
8) Pilot's detection and isolation of fault transient.

Once we identify such components, to get a reliable simulation models, certain issues must be tackled[10], including the determination of the behavioural model complexity level required for the specific case, quantification of the feasibility of acquiring knowledge of the application case and of quantitatively characterizing, verification, validation and accreditation (VV&A) process, and evaluation of the benefits provided by these models with respect to traditional simulators based on average performance levels.

Ergonomic and human factors evaluation of flight deck is a complicated study of the interaction between human and machine and the factors that affect the interaction. Aircraft is to be interacted via interfaces like controls and switches, and feedback information is to be obtained via interfaces. The designs and arrangements of these items may have varying degrees of effects to human factors, hence they may have unknown impacts on aircraft performance and flight safety. Dynamic evaluation of cockpit human factors is the inevitable demand.

To solve the problem, or to generate very large sample sizes of flight data, what indispensable is a fast-time simulation model of pilot-aircraft complex system with considerable flexibility to configure aircraft properties, human capability, and flight environment. This framework aims to represent human performance in complex environments within computer-based discrete event simulation (DES) models using data drawn from empirical studies in the literature and from many military laboratory based studies. Meanwhile, the framework should account for physical environmental factors with system performance as well as the interaction and mediating effects of other variables. The development of a modeling tool that is able to the elaborate of the functional relationships, which will provide a means of hypothesizing the relationships that need to be sought in order to begin to form a modeling tool. Once such a fast-time simulation model is in place, various combinations of aircraft with different characteristics and performance, pilots with different skills and habits, and flight scenarios with nominal and off-nominal cases, can then be tested at fast rate under controllable lead time.

Data analysis on aircraft performance, handling quality, flight safety will not be discussed in depth here though they are ultimate aims to develop human models. Aircraft performance can be defined as a measure of the ability of the aircraft to carry out a specific task. Four aspects of aircraft performance should be included in future effort: performance estimation, performance measurement, performance expression, and performance implication on flight safety. Handling quality are characteristics of an aircraft that govern the ease and precision with which a pilot is able to perform the tasks. Objective and quantitative rather than subjective and qualitative rating of the man-aircraft system is made possible, since human model enables human out of the man-aircraft closed loop. Objective and quantitative ratings can be deduced from data available from very large sample sizes of flight data generated by massive running the fast-time simulation model of complex system; because such flight data not only contain flight status of the aircraft but also contain relevant efforts made by the pilots. Safety margins for intended flight operations can be defined by the space needed to manipulate the aircraft is within valid space and the aircraft's fuel is sufficient. Analysis of flight safety can be summarized as whether the aircraft's performance is scheduled according to the aircraft's handling quality, the aircraft's performance margin and the pilot's capability, to make sure whenever a flight task is accomplished the aircraft is within safety margin.

4 Discussions and Conclusions

The proposed modeling scheme in this paper is essentially data-based approach from complex systems point of view. While we can quantify the human factors to some extent, rigorous analytical is not presented. This is difficult but not impossible. In some cases, the analysis of such systems requires dealing with highly oscillatory functions acquired as a result of measurements. This leads to mathematical difficulties. Integration approach [8] has been proposed based on a set of Hamilton-Jacobi-Bellman equations. The difficulty of this method lies in Hamiltonian estimation which is based on the information accumulated up to the point to reflect dynamic changes in the environment in which the system operates. The solvability of these HJB equations can be developed using mixed finite-element methods or Perron's method. Analytical results along with mathematical formulations are given to verify the effectiveness of the proposed modeling methodologies.

The modeling framework proposed in this paper may have an impact in other field of research, on of which is nuclear power plant. Developing advanced control room in nuclear power plant is the most efficient way to improve the safety and reliability of nuclear power plants. Besides the introduction of advanced technology and equipment, coupling human factors and the control room has been considered in the development of advanced control room significantly. It improves the safety and reliability in nuclear power plant, because the operation is simplified and the operators' load is lightened. The other promising area of application is health care field. Medical research shows that about 2/3 of the complications suffered by hospital patients are due to errors in patient care[7]. Like the aviation industry, the health care field is struggling to develop and implement new approaches to error prevention.

References

1. BASE: Boeing Airplane Safety Engineering, Statistical Summary of Commercial Jet Airplane Accidents - Worldwide Operations, 1959 - 1996. Boeing Commercial Airplane Group, Seattle (1997)
2. Braithwaite, G.R., Caves, R.E., Faulkner, J.P.E.: Australian aviation safety - observations from the 'lucky' country. Journal of Air Transport Management 4(1), 55–62 (1998)
3. McFadden, K.L., Towell, E.R.: Aviation human factors: a framework for the new millennium. Journal of Air Transport Management 5, 177–184 (1998)
4. Buldyrev, S.V., Parshani, R., Paul, G., Stanley, H.E., Havlin, S.: Catastrophic cascade of failures in interdependent networks. Nature 464, 08932 (2010)
5. Newman, M.: Networks: An Introduction. Oxford University Press (2010)
6. Cohen, R., Havlin, S.: Complex Networks: Structure, Robustness and Function. Cambridge University Press (2010)
7. Brennan, T.A., Leape, L.L., Laird, N.M., Hebert, L., Localio, A.R., Lawthers, A.G., Newhouse, J.P., Weiler, P.C., Hiatt, H.H.: Incidence of adverse events and negligence in hos-pitalized patients, results of the Harvard medical practice study I. The New England Journal of Medicine 324(6), 370–376 (1991)
8. Melnik, R.V.N.: Coupling control and human factors in mathematical models of complex systems. Engineering Applications of Artificial Intelligence 22, 351–362 (2009)
9. Byrne, M.D., Pew, R.W.: A History and Primer of Human Performance Modeling. Reviews of Human Factors and Ergonomics 5(1), 225–263 (2009)
10. Bruzzone, A.G., Briano, E., Bocca, E., Massei, M.: Evaluation of the impact of different human factor models on industrial and business processes. Simulation Modelling Practice and Theory 15, 199–218 (2007)