DOCUMENT CONTROL SHEET

	ORIGINATOR'S REF.		SECURITY CLASS.
	NLR TP 96079 U		Unclassified

ORIGINATOR
National Aerospace Laboratory NLR, Amsterdam, The Netherlands

TITLE
Implementations of cause-based pilot model for dynamic analysis of approach-to-landing procedure: application of human reliability to civil aviation

PRESENTED AT
the International Conference on Probabilistic Safety Assessment and Management, Crete, Greece, June 24-28, 1996

AUTHORS	DATE	pp	ref
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DESCRIPTORS

Aircraft landing	Flight safety
Approach control	Human factors engineering
Computerized simulation	Man machine systems
Crew procedures (inflight)	Pilot error
Decision making	Pilot performance
Dynamic models	Reliability analysis

ABSTRACT
This paper presents a pilot study about the applicability of Human Reliability Analysis (HRA) in civil aviation. Implementation of a cause-based model of intentional pilot errors in dynamic analysis of Approach-To-Landing procedure is described. The pilot model focusses on errors as deviations from procedures, and was implemented in DYLAM. The results show that the HITLINE methodology is a suitable tool to perform dynamic HRA in the civil aviation domain.

NLR TECHNICAL PUBLICATION

TP 96079 U

IMPLEMENTATION OF CAUSE-BASED PILOT MODEL FOR DYNAMIC ANALYSIS OF APPROACH-TO-LANDING PROCEDURE: APPLICATION OF HUMAN RELIABILITY TO CIVIL AVIATION

by

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Presented at the International Conference on Probabilistic Safety Assessment and Management, Crete, Greece, June 24-28, 1996.

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Division : Informatics/Flight
Prepared : JFTB/ /JSH/
Approved : RJPG/ /PGAMJ/

Completed : 960208
Order number : 544.202
Typ. : MM

Contents

(10 pages in total)

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Abstract
This paper presents a pilot study about the applicability of Human Reliability Analysis (HRA) in civil aviation. Implementation of a cause-based model of intentional pilot errors in dynamic analysis of Approach-To-Landing procedure is described. The pilot model focuses on errors as deviations from procedures, and was implemented in DYLAM. The results show that the HITLINE methodology is a suitable tool to perform dynamic HRA in the civil aviation domain.

1 Introduction

Safety is an important issue in civil aviation. The public experiences risk in civil aviation by the absolute number of accidents rather than by the accident ratio, defined as the number of accidents per flight. The accident ratio seems to have reached a stable level in the last years [1]. The expectation is that the number of aircraft flights will double in the near future, implying that the accident ratio must halve to maintain the same public experience of safety. The current safety enhancement will not be sufficient to achieve the desired level of safety.
About 70% of all accidents occur in the approach, landing, take-off or initial climb phases of flight. In these phases both the aircraft crew and the air traffic controller play an important role. It is therefore essential to have a very clear understanding of the human causes of the failures. There is a need to assess and quantify the human factor in safety analysis. However, yet insufficient knowledge exists on the human factor in the safety assessment in civil aviation.
The purpose of this paper is to describe a pilot study about the practical applicability of HRA in civil aviation. The depth of the investigation is limited to an existing framework of dynamical analysis developed by the Joint Research Centre (JRC) [2]. This paper focuses on the development and implementation of a cause-based model of intentional errors for the dynamic analysis of an Approach-To-Landing procedure.

2 Context of the study

The specific ATL procedure used in this study was the same one used in an earlier study by [3]. The first part of the ATL was modelled, starting with the descent from cruise level to the passing of the Novarra VOR at 4000 ft.
The basic steps of the procedure considered here are:

* Fl/5/10: extension of flaps to settings 1, 5 or 10 respectively.
* CA: calibration of the altimeter on QNH (actual air pressure at sea level).
* LE: levelling off at 4000 ft.
* CL: reading of the approach checklist, checking the calibration and flap setting.

Use was made of DYLAM as the simulation engine, and of the pilot model developed by JRC, describing the skill-based behaviour, i.e. the actual flying of the aircraft. A deterministic simulation model of the aircraft determined the position and flight conditions of the airplane at all times, with four degrees of freedom.
For details of the context of the study see [3,4].

3 Development of the pilot model

The Pilot model from the JRC exercise was extended to include intentional and additional unintentional errors. A CAuse-based Behavioural model for Flight procedures (CAB-Flight) was developed and incorporated in the JRC simulation to simulate these errors. CAB-Flight is a rule-based model describing the pilot's behaviour during the correct and erroneous execution of procedural steps of the ATL. The model is based on the intentional error model of the HITLINE methodology [5,6].

An <u>error in CAB-Flight</u> is defined as a deviation from a procedure. The following error expressions are identified as part of CAB-Flight for this study:
* **unintentional omission** (OM): The pilot unintentionally does not execute an action.
* **unintentional commission** (UC): The pilot unintentionally executes a procedural step in an incorrect way.
* **intentional commission** (IC): The pilot intentionally deviates from the procedure by performing a different action, because of his perception of what should be done in the current situation.
* **procedural action** (PR): Normally the steps of a procedure are linked to specific conditions to perform it. The procedural action occurs when the pilot decides to perform another step of the procedure first.
* **not monitoring** (NM): The pilot fails to monitor the aircraft variables in order to adjust them. This is not a deviation from a procedure but rather a failure at the skill-based level.

HITLINE assumes that not all errors can occur at all times. Thus, for each procedural action, likely errors are identified by considering the procedural instruction within the context of flight. The results for two steps of the procedure are presented in table 1. It should be emphasised that the principle of such mapping is important. Exact mapping may be different from the one presented here. One of the limitations of the dynamic simulation techniques is the very large size of the resulting dynamic event tree. Thus, mapping selected errors for each procedural step helps to reduce the size of the results.

Table 1. Possible errors.

procedural step	**description procedural step**	**possible errors**	**description errors**
CA	calibration of altimeter, setting to local air pressure	OM	not performing calibration
		UC	wrong air pressure
		PR: F1/5/10	flap setting
LE	levelling flight	OM	not levelling flight
		PR:CL,F1	performing another action

The skill-based level error of not monitoring can occur at every step. It is regarded as temporarily not addressing the tasks of that level. The only possibility for recovery from errors in the model is successful reading of the checklist. Other possibilities for recovery have been left out for reasons of simplicity.

The causal factors affecting errors are modeled using the so-called performance influencing factors (PIFs). These factors are used both qualitatively (to identify likely errors from the set of possible errors) and quantitatively (to estimate relative likelihood for each error). Three categories of PIF are distinguished, related to aircraft, procedure and pilot. Additionally, two types of PIFs are distinguished:
scenario-independent: these PIFs do not change significantly during the development of a scenario. An example is training and experience of the crew.
scenario-dependent: these PIFs change during the development of a scenario. Examples include values of parameters and perceived importance of a system.

From an exhaustive list of PIFs, collected from human reliability models such as THERP, evolutionary models, as well as aviation literature and pilot interviews, a small but relevant set of PIFs was selected for implementation in CAB-Flight.

The essential modelling element of CAB-Flight is formed by the relations between PIFs and errors. These relations are represented in mapping tables, which show the generic and specific rules to generate errors as a function of the PIFs. Table 2 shows an example of a mapping table.

Table 2. Mapping table for scenario-dependent PIFs, pilot related.

Factor	Mechanism	Likely Error
pilot's diagnosis	confusion when something is wrong	more likely to deviate from procedure
perceived importance of certain aspect	fixation on particular aspect / channelling of attention	* unintentional omission * unintentional commission * not monitoring * procedural error
interpretation distance to runway	misdiagnosis	* intentional commission * not monitoring
mismatch between pilot's expectation and aircraft behaviour	confusion / lack of confidence	more likely to follow procedure

Relative likelihoods associated with possible pilot actions, including successful execution of procedural steps and possible errors, are estimated as a function of PIFs. For lack of data which is a common problem in human reliability, use is made of subjective judgement to assign numbers to these likelihoods. Parameters used for quantification are estimated independently for different combinations of PIFs. For simplicity, each PIF is treated in a binary fashion, e.g. experience is considered in terms of experienced or novice crew. For a detailed discussion of the quantification scheme, the reader is referred to [4,6].

When CAB-Flight is linked with a dynamic simulation tool, the error generation model provides simulation of errors for each interaction between pilot and aircraft. Additionally, this model carries variables which account for dependency of pilot action at different times. Three cognitive processes are simulated through the use of mapping tables: (1) check behaviour of aircraft variables against expected trends, (2) determine global diagnosis of aircraft status, (3) formulate expectations about behaviour of variables. The results of the cognitive processes are translated into PIF values which are subsequently used to determine possible actions with associated probabilities as mentioned above. This information is then used by the simulation engine to generate possible branches for the dynamic event tree.

4 Dynamic analysis results

CAB-Flight was incorporated into the pilot model of the JRC simulator. Additional "failure states" were assigned to simulate the different errors. Associated probabilities were generated prior to simulation and written in appropriate data files to be used by DYLAM. It should be noted that whereas CAB-Flight is capable of dynamically calculating probabilities, the scheme was not included in the current version of DYLAM. This has been done in a similar, independent application to dynamic study of nuclear power plants [7].
A dynamic event tree is presented in Fig. 1 which includes the following errors: Intentional Commission (IC), more thrust; Procedural action (PR), calibration of altimeter at F5; Unintentional Commission (UC) (flaps to 20 instead of 10) and omission of checklist reading (OM). A hardware failure is also included in the form of flap failure.

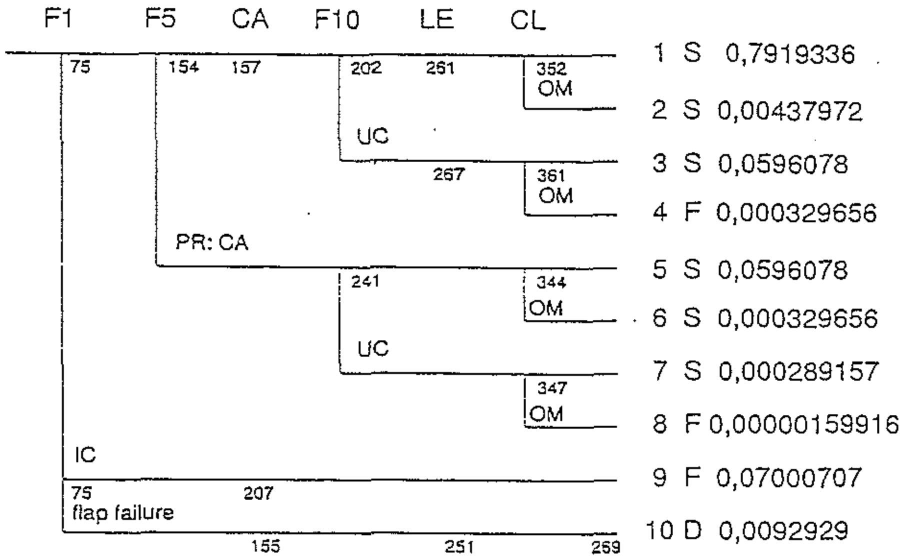

Figure 1 (Dynamic event tree for simulation I)

A comparison with the JRC analysis shows that success probability is 10-40% smaller, which is to be expected since more errors have been introduced to the pilot model of the JRC simulation.

5 Conclusions and recommendations

The results show the feasibility of dynamic human reliability study to analyse pilot errors within the context of aircraft procedures. Moreover, the results show that the HITLINE methodology is a suitable tool to perform dynamic HRA in the civil aviation domain. The benefits of a dynamic HRA for civil aviation are to be expected in the qualitative analysis. It will be useful in the design of procedures, training and man-machine interfaces.
Currently, due to lack of useful data, the quantitative side of the analysis is still a weak point. Still the method itself is simple to use. The determination of the error probabilities is traceable for the user. More PIFs can be added without the need to change the calculation method. The advantage of this method is that all probabilities are conditional, depending on the dynamics of the pilot-aircraft system. This makes it possible to take those dynamics into account.
Future research has to consider the operator model development in more detail, like which PIFs needs to be taken into account. Sensitivity analysis must be part of the model development. In addition, model validation is important.
Future research should also help to determine whether *dynamic* analysis for safety assessment will be cost effective in the design of new aircraft.

Acknowledgement

The authors would like to thank Frederiek Peek for conducting the research with great enthusiasm; Carlo Cacciabue and Giacomo Cojazzi for making it possible for Frederiek to perform part of the research at JRC (Ispra) and providing guidance during her graduation work; and Peter Wieringa for providing valuable remarks and suggestions.

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