
SITUATION AWARENESS AND PROCEDURE FOLLOWING

Gabrielle de Brito and Guy Boy, {debrito, boy}@onecert.fr

1. EURISCO
   European Institute of
   Cognitive Sciences and Engineering
   4 avenue Edouard Belin, 31400 Toulouse
   +33 (0) 5 62 17 38 38

2. Université René Descartes
   Laboratoire d’ergonomie
   informatique de Paris V
   Rue des Saints-Pères,
   75006 Paris

ABSTRACT

Aeronautics procedures are used as prescribed action lists to help human operators remember and follow mandatory steps that guarantee safety, workload and performance criteria. A study of the use of procedures in the civil aviation domain surveyed 207 pilots using four investigation methods, including the observation of 140 hours of full-flight simulator. The results of this study are used to address why human operators of safety-critical systems use, misuse or do not use procedures to keep control of a situation, and how they cope with situation awareness. This paper suggests that new perspectives on design may be required to support the further development of warning systems, the design of procedure and the definition of the pilots’ role.

Keywords

Empirical findings, procedure following, situation awareness, safety-critical systems.

INTRODUCTION

Situation awareness of the human operator is a major issue in the control of current safety-critical systems, such as aerospace systems. It is also a fact that the control of most of these systems is commonly constrained by the use of procedures that are justified by at least four reasons: (i) to enable human operators to face increasing system complexity; (ii) to improve the coordination among human and machine agents; (iii) to support training; (iv) to provide a legal referent.

If the necessity of checklists seems today to be globally recognized by the civil aviation community, they do not agree about their content and their use (Gross, 1995). There seems to be a conflict between the expected use of checklists by manufacturers and airline companies, and the actual use of checklists by pilots (Degani & Wiener, 1990). The problem is that serious accidents involving human factors issues are caused most frequently by incorrect procedure following. Accordingly, the French Civil Aviation Authority (DGAC) has financed a study at EURISCO concerning the use of onboard Airbus operational documentation in cockpits of new generation aircraft. In the United States, Degani & Wiener (1990; 1994) have focussed their study on the manner in which pilots use checklists in normal situations. We have completed this research by studying the use of the procedures in abnormal and emergency situations (systematically quantified analysis) while carrying out an analysis of pilots’ cognitive activity.

The goal of this study is to understand how pilots follow procedures dictated by management philosophy and policy embodied within flight deck procedures. The role of human operators induced by the use of procedures is not uniformly acknowledged in the aeronautics industry for example. Some manufacturers require that human operators consider procedures as prescriptions. Others require that they consider procedures as work support tools. This paper emphasizes a common cognitive contradiction between situation awareness and the role that is assigned to the human operator as a procedure follower. In particular, it examines the real role of the human operator. Indeed, there are two major hypotheses that are commonly put forward:

- H1: If the human operator executes tasks in a procedural mode and if procedures are well-designed, then the human operator does not need to be aware of the work situation (he/she is a procedure follower).
- H2: If the human operator needs to be aware of the work situation and if he or she needs to understand the procedures, then the human operator is a problem-solver.

An experimental study was carried out to show the interrelated roles of human operators and procedures. The methodology that was used was targeted toward proving that pilots do not follow procedures and deducing why. This paper tries to extend the results of this study and proposes a framework of attributes that supports the reasons why pilots cannot be always considered as procedure followers, and the need to keep a well-maintained situation awareness. Recommendations for the design of more appropriate work aids will be provided.

WRITTEN OPERATING PROCEDURES USED IN AERONAUTICS

In the cockpit pilots have a large number of documents at their disposal. Onboard operational documentation consists of technical manuals on aircraft performance, flight maps, flight procedures to be used. All pilots have been extensively trained and have acquired specific knowledge for their use. Operational procedures can cover normal, abnormal and emergency situations. In abnormal situations, pilots encounter the procedure (more or less) for the first time. However, procedures for normal situations have a certain routine nature. To refer to Degani and Wiener (1990) "The principal difference ... lies in frequency of use. The abnormal checklist is very rarely performed by flight-crews during revenue flight; pilots are aware of its criticality, and very much aware that misuse or non-use of the abnormal checklist can transform a routine abnormality into an accident. The same cannot always be said about the normal checklist."

Conditions for using operational documentation

Normal situations

Normal procedures define the basic flight scenario (divided into flight phases), assuming that all systems are functioning and are used correctly. The transition between flight phases is sanctioned by reading the paper “checklist”, intended to control that vital preparation actions have been performed correctly. These checklists are on the back-cover of the Quick Reference Handbook (QRH) published by Airbus Industrie. The actions listed in these checklists are limited to respecting flight safety and efficiency and thus do not take into account the many basic control actions. For example, the checklist used during landing consists of three items whereas the associated normal procedure consists of 20 to 25 actions.

Abnormal and Emergency Situations

Abnormal and Emergency situations appear to be much more complex to deal with than normal situations, not the least being because they can be very different in nature. It would be almost worth processing each failure individually. Abnormal and emergency procedures are used in different and varying situations. Their number is enormous and the difficulty in prescribing instructions is due to the multiplicity of the situations. To reduce the occurrence of human errors, modern aircraft are designed to require as few actions as possible from the pilot in response to any failure or combination of them. These actions are prescribed in the normal and emergency procedures (called “dolists”) which are designed to be followed precisely in order to recover the situation as quickly as possible. These dolists appear on a screen called the “Electronic Centralized Aircraft Monitoring” (ECAM) which presents 262 dolists for abnormal situations and 26 for emergency situations. Its main advantage is to allow direct interaction between the pilot and the system. Dolists appear automatically and indicate to the crew the nature of the failure. Moreover, as the actions are carried out, the lines containing the pertinent information disappear automatically, indicating that the action has been performed correctly. When the system can’t detect the failure, pilots have at their disposal the Flight Crew Operating Manual (FCOM) which gathers all the procedures (normal, abnormal and emergency).

METHODOLOGIES

The theory behind this study is that procedure deviations can be explained by the pilots cognitive activity and the cognitive needs that this gives rise to. We will illustrate our remarks based on the results from the SFACt study using: (i) a analysis of the task and pre-analysis of possible deviations (ii) a questionnaire sent to ten airline companies of different nationality, (iii) observations in a full flight simulator with pilots of new generation aircraft (Karsenty, Bigot, & de Brito, 1995; de Brito, Pinet, & Boy, 1998; and de Brito, 1998) (iv) Group Elicitation Method sessions (Boy & Wilson, 1996)

Analysis of the task and pre-analysis of possible deviations. We started by analyzing the totality of procedures linked to the use of the checklists, and identified in parallel the totality of possible deviations linked to these procedures. The approach that we took to determine these deviations was inspired by the work of Hollnagel, (1993) and the work of Reason (1990), aimed at defining a classification of erroneous actions according to their observable manifestation (or phenotype). This analysis served as a support for elaborating a questionnaire and an observation grid.

The questionnaire. The questionnaire contains 35 questions. The majority of questions consisted of (i) questioning pilots on certain deviations, (ii) justifying replies given. Where possible, closed questions or multiple choice were
used to facilitate the reply. Ten companies using new generation Airbus were consulted and we received a return of 207 questionnaires out of the 606 sent. This relatively high figure reflects pilots’ interest in the subject.

Simulator Observations. To compensate for the difficult access to real situations, all our observations were undertaken in mobile flight simulators (Full Flight Simulators) at the training center "Airbus Training" in Toulouse, with pilots in recurrent training. The possibility of observing pilots in the simulator presents the advantage of analyzing at close hand incident/accident situations.

Group Elicitation Method. Three Group Elicitation Method (GEM) sessions were used to capture consensus and contradictions among pilots on the use of checklists and procedures. During these sessions, pilots gave their viewpoints on the following question: "In the perspective of future electronic operational documentation, please give information concerning: (i) requirements (several layers, color, presentation, logic, details, mental load, etc.) (ii) problems and issues involved; (iii) right balance between paper and electronic documentation ».

The consecutive use of several methodologies seemed to us relevant in understanding the characteristics of following written operating procedures, and thus allowing an explanatory approach of the activity.

ANALYSIS AND DISCUSSION
The analysis, carried out using complementary methodologies, reveals that the large majority of pilots recognize the importance of operating procedures. Eighty percent of pilots questioned consider them to be important or very important. However, if we look at pilot satisfaction with current written operating procedures, the results are more mixed. Only 38 percent of pilots are satisfied with their contents, comprehensibility, presentation, size, adaptation to operation environment, ease of access to dolists. These results show that while pilots need procedures currently and they are not well adapted to their needs. Although cooperative crew work has positive effects, it only partially corrects pilot error. This is why it is important to list the reasons for dissatisfaction with written operating procedures and to explain the most frequent deviations.

Pilots state that they generally use consistent behaviors when using written instructions, but at the same time admit to deviations from instructions generally in exceptional circumstances. They justify this behavior by three major classes: (i) the need to manage a different operational situation from what they envisaged (ii) loss of control of the activity, and (iii) the need to better understand the situation.

Manage a different operational situation
Flight deck procedures are pre-defined with respect to a class of situations. Each situation class can be very specific, sometimes unique, to general. As already seen, dolists used in abnormal situations may be executed when pilots judge that it is the right time. In contrast, emergency dolists must be started immediately. We have found that 92 percent of surveyed pilots think that aircraft safety is more important than initiating any dolist independently from the urgency of the situation. This point is clearly made to support dolist execution delays: only 39 percent of surveyed pilots claim that they never delayed a dolist. When a pilot (usually the captain) makes the decision to assure immediate safety of the aircraft, he or she is in change of the trajectory tracking task, i.e. speeds, heading, safety altitude, attitude, roll, yaw and navigation. Some pilots strongly advocate the fact that it would be crazy to risk an accident by being obliged to follow a written operating procedure when the normal trajectory of the aircraft is not appropriate or is degrading. Delaying the execution of a written operating procedure cannot qualify as a deviation but it comes as a result of a conflict resolution that pilots obviously needed to process. We then admit that pilots incrementally re-define emergency situations almost systematically. Consequently, intrinsic properties of real flight situations may make the expected applications of dolists partially or totally impossible. This is confirmed by the fact that pilots seems to feel a contradiction between the natural reactions to the emergency of the situation and procedure following that is necessarily slower. This contradiction may lead to the non-execution of the written operating procedure (at least at first), and instead of executing some items from memory. Memory-based execution can also be a reaction to the fact that information provided in the written operating procedure is inappropriate or incomplete. In addition to pilots' knowledge and know how, the central issue is the consistency between paper procedures and electronic procedures. Paper procedures make some information explicit. In contrast, electronic procedures only present a list of actions to execute. It is the lack of information and the distance between the expected situation and the real situation that forces pilots to take action and incrementally construct in real-time the procedure that they need to execute.

Activity control loss
Normal checklists represent only a very small part of the rules and procedures that crews need to follow during a flight. Routine use, interruptions, and the operational context of the flight (radio, cabin crew, etc.) are often the main cause of activity control loss. In turn, activity control loss may be the cause of forgetting and poor cross-checking.
Curiously, the aviation community tends to consider that such operational context disturbs checklist execution, whereas checklists are artifacts that actually disturb pilots’ “natural” operations. It would be difficult to understand the relations between checklists and operations management without taking seriously into account time management. Time management is a constraint that comes from two types of requirements: commercial and technical. The commercial requirement constrains the pilot to satisfy a time schedule in a highly competitive environment, where air space is becoming overcrowded. The technical requirement constrains the pilots to a continuous control loop and a finite flight time where there is no room for waiting or thinking at leisure. Most decisions need to be made quickly. This is why experience, expertise and self-confidence are key factors for pilots.

The time constraint is crucial and pilots are permanently busy managing it. In addition, they need to manage another constraint dealing with procedure management. Procedures are designed to be executed linearly without interruptions. They are supposed to be an integrated part of a flight organized into flight phases of a standard sequential scenario, and are taken into account in the procedures.

Despite these major operational interference’s leading to the non-application of prescribed procedures, 98 percent of pilots consider that checklists and dolists provide valuable during current flight management situation awareness assistance.

The resulting issue seems to be the scheduling of prescribed tasks. Problem solving under time constraints is a cognitive problem. For example, when an operational event forces the pilots to interrupt a checklist sequence, they use various strategies that depend on the duration of the interruption, or even its a-priori estimation. We found that forgetting items was more specifically due to the nature of the interruption. For example, when the ATC interrupts the pilots during the reading of a checklist, 68 percent of the pilots forget to complete the checklist appropriately. When the interruption is caused by a failure, 89 percent of pilots forget to complete the checklist.

**Understanding the situation**

As the pilot is ultimately responsible for failure management regardless of the nature of the warning system, it is important that he or she understands what the automation is doing, why it is doing this and what it intends to do next. To satisfy these commonly asked automation questions (Weiner & Curry, 1980) the design engineer must produce an interface concept capable of communicating this information effectively to the pilot. The same principle applies if the pilot is following instructions “issued” by automation (as we find in the form of electronic checklists) where it is important that pilots understand what they are actually doing to the system (Hicks & de Brito, 1998). However as the failure sensing and diagnosis functions are already automated in modern aircraft, these variables are not normally known by the pilot, who without knowledge of the cause of the failure context may miss the effect of automated actions or fail to understand what they observe.

The lack of understanding of the actual situation and prescribed action rationale may lead pilots to use procedures inappropriately. It is difficult to infer from our results how many pilots execute prescribed actions without questions. For most pilots, understanding a prescribed action is constructing informational context that makes the situation relevant. This context may include (1) a sufficiently precise diagnosis that will highlight the interest of prescribed action when it is related to the desired state of the systems such as represented by pilots; (2) a more global representation of interconnections among systems capacities and situation awareness.

To summarize pilots need to understand what they need to do by using three cognitive functions according to their interest. These cognitive functions are used in real flight to compensate procedure limitations due to their design in a different context. More fundamentally however they are mandatory assets of pilots who need to keep control of the situation in all circumstances (Hollnagel, 1993) Pilots need to know what they are doing all times and anticipate the consequences of their actions. It follows that many deviations from prescribed procedures are caused by a conflict between what is required and what the pilot needs to do to keep control of the situation. This may lead to serious consequences. We make the assumption that helping pilots maintain a satisfactory level of situational awareness and prescribed actions rationale, will contribute to reducing deviations that lead to serious consequences. The objective is thus to determine what, when and how pilots need to understand in order to act.

**What do pilots need to understand?**

It is however misleading to think that pilots should be aware of everything in order to use prescribed rules. System complexity and the amount of information that needs to be assimilated are very high and require prior definition of the level of understanding. Two possible approaches are: (i) determining what pilots need to understand before applying an abnormal or emergency procedure, (ii) determining what pilots are required to understand. This distinction is necessary since the pilot may not know the he/she needs certain information in order to fully understand the logic of a procedure, for example.
When and how do pilots need to understand?

Since flight situations are highly dynamic, it is almost impossible to categorize the level of situation awareness for all prescribed actions. Most actions can be started with a minimum level of situation awareness (Hunt & Rouse, 1981); situational awareness improves during actions and even after. It is thus necessary to provide the pilots with appropriate means that enable them to understand what is going on and what they should do. Pilots must be provided the means to understand these three different phases, which means dealing with each phase separately.

Understanding before the action. Training plays a vital role of providing pilots with the knowledge necessary to understand rapidly what is happening during a failure and what implications failure will have. However, as the current trend is to reduce the amount of initial training, this recommendation could be applied during recurrent training. Human-machine interfaces are also of importance in providing pilots with an up-to-date representation of system status (i.e., situation awareness) no matter what the situation.

Understanding during the action. This mode of understanding relies on the feedback from actions, but not just not simply the confirmation that an action has been carried out. Pilots wait for this feedback in order to better understand what is happening and to obtain a more global vision of the aircraft’s status. Thus, compared with current practice, they require more informative feedback on possible consequences of an action on different levels.

Understanding after the action. This mode of understanding has the advantage of providing pilots with more time, which could allow getting additional information.

Given the possibility of using these three different phases, an essential question is to determine what information should be rapidly finished and what information can remain momentarily unknown without leading to a deterioration in pilots' performance.

CONCLUSION

The above results show that three main activities support and improve the situation awareness in safety-critical environments such as aerospace. These activities are recognized: situation management, control and understanding the current situation.

We have observed that onboard operation documentation provides a means of training and assisting users in carrying out their tasks. It must be efficient and easy to use. However, the contents of this type of documentation should be used to redesign human-machine interfaces better adapted to users. There is an important relationship between the interface and its procedures. The more an interface allows for easy system use, the less the user should require procedures; in a sense the interfaces affordance renders procedures unnecessary. Conversely, the more an interface is difficult to use, the more the user will require procedures. Thus, there is an industry trend toward specify procedures that are easier to use. Moreover, users often need to understand the rationale of suggested or required actions.

Through their training and experience pilots develop a mental model of aircraft systems. When pilots need to manage failures in aircraft systems, it is their mental models that guide their understanding of causality and expectations of effect. Encouraging the development of a mental model in a pilot that will give him/her a high degree of reasoning power in failure situations must be a primary objective of failure management training and for him/her to achieve this he/she must understand system automation behaviour (Hicks & de Brito, 1998). Designing a failure management system that is consistent with this principle and that complements this training must be an equally important objective.

It is important to recognize a link between a pilot’s role in failure management, his/her task definition and his/her subsequent awareness of system status. Our study has shown that pilots do not behave currently according to the model of an "ideal” executant in abnormal and emergency situations: they seek to understand before acting. Beyond this general statement, a major conclusion of our work is that the majority of pilots interviewed acknowledge that understanding a prescribed action leads to representing the context that makes the action relevant. This context may include (i) the distance between the perceived state and the desired state of the systems that enables the pilot to give meaning to prescribed actions; (ii) a global representation of the interconnections among systems and flight objectives in order to evaluate possible consequences of a failure on the rest of the flight; (iii) other possible actions that, jointly exploited with the pilot’s knowledge of system functioning and the operational environment status, will enable the pilot to judge the degree of relevance of the prescribed action.

In the future, the design engineer may limit the goal of interface technology and crew training to support a ‘stripped down’ rather than veridical mental model of automation, concentrating resources instead on designing a means of communicating an explanation of the automation’s current actions, rationale and future intentions to the pilot. Indeed, the methodology of "cognitive function analysis" proposed by Boy (1998) offers a framework to enable a design team to anticipate and document cognition induced by both the design process and designed artifacts. It provides members of the design team with a common frame of reference and enables the team to share their views on the artifact being designed.
ACKNOWLEDGEMENTS

The authors wish to thank David Novick for his comments on this paper and Helen Wilson for her precious help. The authors like to thank the pilots and airline companies who answered the questionnaire with such care and who accepted my presence in the simulator. The mass of information gathered is extremely valuable as a result.

REFERENCES


RESUMÉ

CONSCIENCE DE LA SITUATION ET SUIVI DE PROCÉDURES ÉCRITES

Les procédures écrites utilisées en aéronautiques sont conçues comme une liste d’actions pour aider le pilote dans l’exécution des actions visant à garantir un niveau maximal de sécurité ainsi qu’une performance optimale. L’étude de l’utilisation des procédures opérationnelles Airbus a permis de mettre en évidence les raisons pour lesquelles les pilotes n’utilisent pas les procédures comme prescrit. Trois raisons principales sont avancées : tout d’abord, les pilotes doivent gérer des situations opérationnelles différentes de celles prévues dans les procédures ; de plus, suivre pas à pas une prescription ne leur permet de garder le contrôle de l’activité ; enfin, les pilotes ressentent le besoin constant de comprendre la situation dans laquelle ils se trouvent. Cet article suggère de nouvelles perspectives pour la conception des systèmes d’alarms, pour la conception des procédures opérationnelles et pour la définition du rôle du pilote.