MANAGEMENT OF MULTIPLE TASKS: COCKPIT TASK MANAGEMENT ERRORS

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Abstract

A flightcrew's behavior is affected by the set of concurrent tasks they are attending to at any given time, and system performance is dependent on the availability of both human and system resources. If the demands of concurrent tasks exceed the flightcrew's supply of resources or the resources are improperly allocated, i.e., poorly managed, then the flightcrew is likely to exhibit degraded performance, which may adversely affect safety and effectiveness of the aircraft system.

This research adopts the view that a flightcrew does not only have to perform tasks, but manage them as well. It assumes that proper task management can be crucial to the successful completion of the flight mission. From this perspective, a framework for Cockpit Task Management (CTM) has been proposed. Based on this framework, a set of CTM errors will be derived from aircraft accident/incident reports and flight simulator experiments. The results of these studies will be used for developing the specifications for a PVI which facilitates the CTM functions. The remainder of this paper describes our research.

The Changing Role of the Flightcrew

Rapid advances in hardware and software technologies along with the quest for safer flight and economical concerns, among other thrusts, have pushed today's aircraft toward higher levels of automation [1, 2]. Even though aviation human factors experts have mixed feelings about this concept, virtually all new generation airplanes are built around fly-by-wire and glass cockpit concepts [3]. As a result of this trend, the role of today's pilot has changed from that of a moment-to-moment controller to that of a system monitor or supervisor. Also, cockpit tasks have become more cognitive in nature. Combined with the increased level of automation in today's cockpit, the increasing air traffic density, more regulations, and poorly integrated cockpit systems make today's flying operations more difficult than before.

A typical commercial flight mission can be decomposed into taxi, take-off, climb, cruise, approach, and landing phases. Given that the gross structure of a flight mission does not change, the nature of tasks that today's pilots must perform has changed qualitatively due to the level of automation [4]. For example, the computer-based flight management systems in modern airplanes provide greater reliability and efficiency, but they also require the pilot to perform inflight programming, which is a new function that places considerable cognitive demand on the pilot. This is especially true during the approach phase of flight, in which the pilot is already taxed by the huge demand of just flying the airplane. Head-down programming in the case of a change of runway can pose a significant safety problem.

There is no doubt that automation does aid the pilot when it functions correctly, and today's airplanes have the ability of flying automatically from take-off to landing without human intervention - as long as nothing goes wrong and plans do not change. But it is also important to realize that automation can fail and plans do change. In any case the pilot must monitor the performance of the automated equipment. For those times when the pilot relies on automation to control the aircraft, the threshold arousal for detecting a subsystem failure is higher than when the pilot controls the aircraft manually. The trend is that more and more automation will be introduced into the cockpit [5]. But fewer cockpit crew members will be present. This implies that each crew member will have more subsystems to monitor and at least occasionally control.

Besides the fact that the pilot's tasks have changed, today's pilots have to adapt themselves to a more dynamic environment of flight operations. First, the great demand for air travel has brought more airplanes into service even though there has not been a commensurate increase in the number of major airports. This implies that airways have become more congested. Second, new regulations such as noise abatement requirements and proposed smaller vertical separations of airplanes have put greater demands on flight operations in terminal areas. Third, pilots may be requested to transition among a variety of different airplanes in which the displays and controls are significantly different. And the transition from a traditional fly-by-mechanic to a fly-by-wire aircraft or the other way around may influence the pilot's performance [6].

Although some efforts have been devoted to integrate automated equipment in the cockpit, such as EICAS (the Engine Indication and Crew Alerting System) for integrating engine warning messages, most automated cockpit equipment is still operated in an independent, device-oriented manner. Particularly, a new automated device is usually advocated to be installed into the cockpit following a new type of air accident. And its purpose is solely devoted to be functioning

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for such an accident. "And flying is complex enough that everything that can happen has not yet happened." [7] Also pointed out by Wiener [8], the one-box-at-a-time approach to installing automated equipment requires pilots to integrate vast amounts of information from a variety of different sources.

From the above discussion, we realize that the demands on today's pilots are not necessarily reduced because of the increased level of automation. On the contrary, when unexpected events occur in the cockpit, the pilot may have to perform even more tasks to cope with the situations. And accidents/incidents are the most likely outcomes if the pilot fails to effectively manage these tasks.

Cockpit Task Management

Given that flightcrews usually perform multiple, concurrent tasks in flight missions, the concept of Cockpit Task Management (CTM) has been proposed by Funk [9]. CTM is defined as the management of limited human and cockpit resources so as to allow effective task initiation, task monitoring, task prioritization, resource allocation, task interruption, task resumption, and task termination. Using this framework, we propose that with a better management of the multiple, concurrent tasks, a flightcrew's performance can be improved.

Funk's normative theory of CTM is based on the concepts of systems, goals, and tasks. A system is an object with input, output, and state. A dynamic system is a system whose states change over time. A system behavior is a time series of input, output, and state. A goal is a set of desired system behaviors. Finally, a task is a process carried out to achieve a goal, i.e., a task is a goal-directed activity. Using theories derived from cognitive psychology, the performance of a task depends on the available cognitive resources [10]. If the supply of a human's resources does not meet the task demands, task performance will be degraded. While performing multiple, concurrent tasks, the human also needs to use some of these resources to decide how to manage the tasks. This all leads to a recognition for the need for effective task management.

There are at least seven functions performed in CTM: task initiation, task monitoring, task prioritization, resource allocation, task interruption, task resumption, and task termination. Task initiation is the starting of a task when the appropriate conditions are met. Task monitoring is to assess the status of active tasks. Task prioritization is the ordering of tasks according to their immediate importance to achieving mission goals. Resource allocation is the assignment of limited resources, both equipment and human, to tasks so that they can be accomplished. This may require that certain lower priority tasks be interrupted and later resumed when resources become available again. And these are termed task interruption and task resumption. Lastly, task termination is the removal of a task from contention for resources. This may occur due to goal accomplishment or the determination that a goal is no longer relevant or cannot be achieved.

CTM Errors

The concept of CTM will prove to be valuable only if it can be used to explain, predict, or reduce cockpit errors. An error can be defined as any process that conflicts with the current goal. We believe that if we can identify actual CTM errors, we should be able to design useful tools and procedures to facilitate the CTM and prevent such errors from happening again.

A CTM error in the context of the above framework is an error which degrades the effectiveness of task management. For example, to begin an inflight engine restart task above the engine restart envelope is an error of task initiation, since one of the initiation conditions for an inflight engine restart task is to first descend to a certain altitude for adequate air density. Such an error in initiating a task can influence the initiation, resource allocation, and termination of other concurrent tasks, which can lead to further problems.

In general, a typical way to study errors usually falls into the following pattern: what, why, and how. The first step often starts with a human operator model describing the operator's behavior. From this model, the second step is to define a set of error classification schemes for classifying the errors, which is to find out 'what happened'. The third step is to derive causes and find out 'why did it happen'. And finally, countermeasures such as design guidelines are proposed to prevent these from happening again. A variety of studies using this general approach has been performed in different domains [11 - 13]. With regard to flight operations, in specific, there are four ways to study human errors: (1) direct observation, (2) post-accident analysis, (3) voluntary reporting system data analysis, and (4) lab experiment using flight simulators [12].

The first method for studying errors is direct observation, which is the most straightforward way. To use such method effectively, the observer must be an expert in piloting tasks and must understand the whole spectrum of errors that can occur. Some studies for pilots transitioning to advanced cockpit have been successfully performed [6, 14]. Although it is one of the best ways for studying errors, it also has some disadvantages: (1) the observers can make (observation) errors themselves, (2) the observed operator's behavior may be influenced by the presence of the observer, and (3) the observer may not be able to control important variables.

The second method is post-accident analysis. This analysis usually generates much data regarding the descriptions of the accident, but the desired information may not be retrieved, since aircraft accidents are often total disasters, in which vital information about crew error is often lost and causality of error often cannot be determined. Therefore, the opportunities for studying errors in this manner are severely limited.

The third method for studying errors is through the database of incident/accident reports. The Aviation Safety Reporting System (ASRS) is a voluntary reporting system developed and operated since 1976 by NASA for the FAA [15]. More than half a million reports made by pilots, air traffic controllers, and others have been analyzed and stored in the database. These data are useful in many ways. The most important to us is that each report may be made by the operator who made the errors, and therefore provides first-hand information regarding how and why the errors occurred. But it also has its drawbacks. For example, one of them is its potential lack of randomness [12]. And the other is the lack of consistent level of detail describing what has happened due to huge variation across the individual reporters. The latter usually makes the analysis more difficult, simply because for the same type of incident (e.g., engine fire - return to destination airport), there may be huge differences between different reports.

The fourth method for studying error is to conduct lab experiments using flight simulators. In contrast to the method of direct observation, this method has the advantages of allowing the control of variables of the experimental setting. Drawbacks to simulation include the potential for over-simplification.

The current research is designed to investigate CTM-related errors. Once these errors are identified and analyzed, a set of specifications for developing tools and procedures to facilitate CTM will be derived. In this paper, a preliminary set of specifications for a Pilot-Vehicle Interface is proposed. Given the framework provided by Funk [9], the approach of this research includes: (1) analysis of aircraft accident reports provided by NTSB (National Transportation Safety Board), (2) analysis of the ASRS database, and (3) analysis of data from simulation experiments.

The aircraft accident reports provided by NTSB in the last two decades will be used as one source for studying CTM-related errors. We will focus on those accidents in which errors can be explained in terms of improper task initiation, task monitoring, task prioritization, resource allocation, task interruption, task resumption, and task termination. In studying these reports, we realize that no accident can be explained in terms of a single error. Accidents caused by "pilot error" are usually the result of a series of wrong information acquisitions, decisions and actions [12]. We also realize that the seven functions of CTM are very much interrelated. That is, the delay of some task's initiation will definitely affect the initiation of successor tasks. Therefore, we will attempt to extract all errors related to the seven functions from the accident reports and provide a summary from the findings.

Since the ASRS database contains a broad range of possible errors, virtually all kinds of questions regarding aviation safety can be asked of it. It is possible that the search for CTM errors will result in nothing if the study is not properly designed. Therefore, we must carefully design the inquiry to yield useful output. For example, one topic for further investigation has been derived from the analysis of an aircraft accident report [16] is inflight engine restart. This direction may lead us to understand more about how and when a pilot initiates and prioritizes such a task.

We have built a PC-based flight simulator in our laboratory which simulates a generic, two-engine airplane with simple six-degree-of-freedom aerodynamics. A collection of tasks will be developed for the approach and landing phase of a typical flight. We will train subjects to use the simulator and ask them to fly the approach and landing. During the simulations we will record the subjects' behavior using both computer-based methods and video tape. After the experiment, we will analyze the data to identify CTM errors.

A set of Cockpit Task Management System specifications will be developed following the analysis of accident/incident reports and simulation experiments. These specifications will be used to develop tools and procedures which facilitate the CTM functions based on the CTM errors.

Progress

We have identified a number of aviation accidents or incidents which involved CTM errors. As mentioned before, we cannot conclude the CTM errors were the only reasons for the accidents. And the pros and cons of an accident can easily be interpreted in different ways using different framework. For example, in one of the accidents provided by Wiener and Curry [1], the Swift Aire Lines accident [17], in which the crew had mistakenly shut down the left (good) engine when they detected that the right engine had autofeathered (a false alarm, too) during the climb. The term 'Automation-induced error compounded by crew error' was used to describe it. And such an error will fall under the 'incorrect' category of the task initiation level in our taxonomy (Table 1). If these errors could have been prevented, the accidents could possibly have been avoided.

One example of the results of a CTM error occurred in 1972, when an L-1011 aircraft crashed while on approach to Miami International Airport. The crew was allocating all of its resources to diagnosing a faulty gear-down light-bulb instead of allocating adequate resources to monitoring the altimeter. As a consequence, the crew failed to notice that the aircraft was slowly descending. After the crash, which killed 99, investigators determined that the autopilot was inadvertently disengaged and the aircraft was set to a slow descend mode [18]. This case shows that the crew didn't manage its tasks effectively by allocating adequate resources to a high priority task (flying the airplane).

Another example in which a CTM error was a contributing factor to the accident occurred in 1985, when a China Airlines B-747SP lost thrust on its No.4 engine 300 nautical miles northwest of San Francisco. As is recorded in the NTSB report [16], the captain commanded the flight engineer to restart the engine at an altitude of 40,000 feet, well above the maximum inflight engine restart envelope. And he did not manually take over the control of the airplane, which was recommended by the engine operation manual and his training, but let the autopilot control the airplane during that period. The incorrect decision to restart the engine prematurely was an error in task initiation. Fortunately, though the aircraft fell over 30,000 feet the captain was able to recover the airplane before impact and later landed safely.

Preliminary Results

As a preliminary study, we have reviewed 14 NTSB air accident reports published in the last ten years that are relevant to this research. To select these reports, we went through abstracts of NTSB air accident reports (AARs) during this period. Only those accidents which we both agreed were CTM-related were selected. Once selected, each report was further analyzed using an error taxonomy to categorize the type of CTM errors (Table 1). This taxonomy is divided into two levels: general and specific. At the general level are the seven CTM functions. The specific level are the kinds of errors that can occur under the general category.

Many of the specific level categories can be found in Rouse and Rouse [13]. But we believe using the concept of tasks not only provides a coherent representation of the context, but offers a convenient way to design specifications of countermeasures for coping with the problems. The results of a preliminary analysis of the 14 accidents are presented in Table 2.

Table 1: A Preliminary CTM Error Taxonomy

General level	Specific Level
Task initiation	early
	late
	incorrect
	lack
Task monitoring	excessive
	lack
Task prioritization	high
	low
Resource allocation	high
	low
Task interruption	incorrect
Task resumption	lack
Task termination	early
	late
	lack
	incorrect

Interestingly, 39% of the total errors are in the task initiation categories. In other words, not correctly initiating a task contributes to over one third of the errors in these accidents. An initial attempt for deriving the cause of such errors indicates that pilot's knowledge of the aircraft or the procedures is usually limited in those tasks when abnormal conditions occurred. This lack of knowledge is also one of the causes proposed by Rouse and Rouse [13] in flight operations.

Based on our preliminary studies, an initial set of requirements for a pilot-vehicle interface (PVI) to facilitate CTM has been developed. Basically, such a PVI needs to:

1. Recognize what task to perform and when to initiate it. Help the pilot configure cockpit resources for the task. If the pilot fails to initiate the task, remind him to do so.

2. Help the pilot prioritize the current set of tasks. Remind him of the most important ones.

3. Recognize when a task should be terminated.

4. Tailor displayed information for the current tasks.

This list is by no means complete, and more requirements will be added as this research proceeds. Future research will involve the development and evaluation of a Cockpit Task Management System that supports these requirements.

Table 2: Results of a Preliminary CTM Error Analysis

	Number of Errors							
Report no. NTSB-AAR-	Task Init.	Task Mntr.	Task Pritn.	Rsrc. Alctn.	Task Term.	Task Intrpt.	Task Resmp.	Sum
73-14 (L-1011)	0	1	1	1	0	0	0	3
80-1	0	1	0	0	0	0	0	1
80-8	1	0	0	0	1	1	0	3
80-10	0	0	0	0	0	0	0	0
81-4	1	0	0	0	0	0	0	1
81-13	0	0	0	0	1	0	0	1
82-8	2	0	0	0	1	0	0	3
84/12	1	0	0	0	0	0	0	1
84/15	1	0	0	0	1	0	0	2
85/03	1	1	0	1	1	0	0	4
86/01	1	1	0	0	0	0	0	2
86/03	3	0	1	1	0	0	0	5
86/06	0	0	0	0	1	0	0	1
86/07	0	1	0	0	0	0	0	1
Total:	11	5	2	3	6	1	0	28

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