CONCURRENT TASK DEMANDS IN THE COCKPIT: CHALLENGES AND VULNERABILITIES IN ROUTINE FLIGHT OPERATIONS

Dr. Loukia D. Loukopoulos
NASA Ames Research Center / U.S. Navy
Moffett Field, CA

Dr. R. Key Dismukes
NASA Ames Research Center
Moffett Field, CA

Dr. Immanuel Barshi
NASA Ames Research Center
Moffett Field, CA

To characterize the concurrent task demands of routine cockpit operations, we observed multiple flights from the jumpseats of two major airlines, reviewed the airlines' written guidance and training materials, and analyzed ASRS incident reports. We found that pilots must often perform several tasks concurrently, and that they are frequently interrupted, which forces them to interleave, suspend, and defer components of tasks. Written procedures and classroom training inadequately characterized the concurrent nature of cockpit tasks and provided little guidance on how to manage concurrent demands. This report, using illustrations from the taxi-out phase of flight, is part of a larger study of the cognitive demands of concurrent task management. We also discuss potential countermeasures.

Introduction

In the course of even the most routine flight, each cockpit crew member is frequently required to manage several tasks concurrently. Problems with concurrent task management (CTM) are a significant source of crew error, and have contributed to both accidents (Chou, Madhavan, & Funk, 1996) and incidents (Dismukes, Young, & Sumwalt, 1998). CTM difficulty is only partly a matter of level of workload; even when sufficient time exists to perform all tasks, individuals make errors as they attempt to interleave tasks competing for attention. Recognizing the vulnerabilities associated with CTM in aviation, researchers have recently focused on this issue (e.g., Funk, 1991; Raby & Wickens, 1994; Rogers, 1996; Schutte, & Trujillo, 1996). However in order for researchers to direct their studies effectively and to develop ways to reduce vulnerability to CTM errors, we must first thoroughly characterize the nature of cockpit CTM tasks and the demands those tasks place on human cognition.

Our ongoing study attempts to provide this characterization. We are collecting data from jumpseat observations of cockpit activities in normal airline operations, from airline training and flight operations manuals, and from Aviation Safety Reporting System (ASRS) incident reports and National Safety Transportation Board (NTSB) accident reports. We previously reported preliminary observations of CTM issues in the preflight phase of operations (Loukopoulos, Dismukes, & Barshi, 2001). We now have more extensive data and discuss the cognitive demands imposed by common patterns of concurrent tasks. In this report, we use examples from the taxi-out phase, the period extending from pushback from the gate and engine-start to the time when the aircraft reaches the hold-short line and is cleared for takeoff. Focusing on a particular flight phase illustrates general principles we believe apply to all phases of flight.

Methods

We observed training at two major U.S. passenger airlines and analyzed flight operations manuals (FOM) and other written material providing operational guidance for crews. This step enabled us to better understand the events and actions we observed in line operations and provided information on the ways in which training and formal procedures prepare crews and guide their management of concurrent tasks.

To date, the first author has conducted jumpseat observations on 60 flights, ranging from 1-4 hours and spanning major and minor airports nationwide. Some flights were flown consecutively by the same pilots, others involved a change in crew, and one crew was "shadowed" for the duration of their three-day trip (11 flight legs). The second and third authors also conducted many jumpseat observations which have informed our study. All observations were carried out on the Boeing 737, a popular aircraft among U.S. air carriers, whose jumpseat affords an excellent view of cockpit controls and displays and pilots' actions. Radio and intercom communications were monitored with a headset. In addition to the pilots' actions and verbalizations, pilots' interactions with other personnel (e.g., ramp agents, ground crew, and air traffic controllers) were noted. Quantitative data were not collected because the volume and pace of cockpit activity are far too extensive to capture in note taking. Rather, our approach is ethnographic: The observer was immersed in the cockpit environment and took notes on significant events, activities and interactions of personnel. During most of the flight, the observer attempted to be as non-obtrusive and silent as possible. However, during the low-workload portion of cruise flight and after the end of flights, we were able to ask questions to help understand what was observed.

In addition, we have collected a large sample of ASRS reports by searching the database for terms relevant to CTM identified in the course of jumpseat observations. Examples from these reports are provided here to illustrate specific points.

Results and Discussion

Airline cockpit operations are highly scripted. Pilots are given formal written procedures that prescribe in detail how the aircraft is to be operated in each phase of flight, who is to do what, and in what sequence. These procedures list the sequence of actions pilots must take in setting each switch and control and checking the status of each aircraft system. The procedures also provide more general direction on how the aircraft is to be flown, how the automation is to be used, and how the crew will interact with other personnel in the system. Airlines use a procedural "flow" and checklist system. The crew sets the aircraft systems from memory and then checks that the most critical ("killer") items have been accomplished by reading from a checklist. This scripted approach to operating procedures has major advantages. Crews must often accomplish a very large number of procedural steps in a short time. Scripting allows pilots to perform procedural tasks consistently in line operations so that performance becomes largely automatic with practice; execution is fluid and rapid and requires little mental effort. This set pattern of execution also helps prompt pilots to remember what must be done at each stage.

Comparison of written materials with actual line operations.

We found that airline formal procedures and classroom training in use of those procedures give almost no indication of the substantial concurrent task demands we observed crews to actually experience in line operations. When compared to real-life operations, the procedures and training are misleading in three respects: they give the impression that the procedures are linear, that the pilots have full control of their execution, and that the procedures flow uninterruptedly.

1) Pilots are often called upon to perform two or more tasks concurrently in order to respond to operational demands. The first officer, for example, may be checking that the captain taxies the aircraft down the correct taxi route, while also monitoring the radio for possible amendments to the taxi route, sequence, or takeoff runway, and perhaps also finishing up performance calculations left-over from the preflight phase. However, the written material describes such procedural steps in a serial manner, as if they can all be performed sequentially, with each being completed before the next is initiated. To some extent this problem may arise from the serial nature of language, which leads the writer to describe tasks sequentially rather than in parallel. However we saw no evidence that procedure writers have tried to compensate for this misleading impression by explicitly discussing circumstances in which two or more tasks must be interleaved concurrently.

2) Crews are sometimes unable to execute a procedural step at the point at which it occurs in the written procedures, either because the larger situation makes it inappropriate to execute that step at that moment or because information necessary for execution of the step is not yet available. An example of the former occurs during winter operations if the captain decides to defer setting flaps to takeoff position so that taxiing on slushy taxiways does not throw freezing slush up on the flaps. The procedural step of extending the flaps, which normally occurs right at the beginning of the taxi sequence, now has to be recalled and performed at the end of the taxi and prior to takeoff, at a time the crew is often busy with the last procedural steps to prepare for takeoff. An example of the latter occurs if the first officer has to hold off on entering data into the flight management system before taxiing because a final passenger count or other aircraft load data from the cabin crew or dispatch is not yet available. The crew is now forced to recall and perform this head-down activity when the data becomes available during taxi, at a time when they should be devoting their attention outside the cockpit window. In addition to disrupting the normal flow of procedures, these situations impose additional workload on the crew, as will be discussed later.

3) Crews are frequently interrupted, especially by other personnel, while they perform procedures. Preflight preparation is rife with interruptions from gate agents, ground personnel, flight attendants, and others (Loukopoulos et al., 2001, 2002), however all phases of flight are affected. For example, crews must monitor and respond to radio communications while performing taxi duties. But each communication, which must be carefully screened to determine its relevance, is an interruption. The

timing of interruptions and the nature of response required is largely unpredictable, which means that the crew has little chance to plan in advance how to interleave the interrupting activity into the ongoing flow of tasks.

Cognitive demands of concurrent tasks management.

Figure 1, derived from ASRS incident reports, illustrates the range of errors pilots have committed during taxi-out. These reports were selected because the errors appear to be associated with concurrent task demands. We can best understand the cognitive challenges imposed by concurrent tasks in terms of two distinct, though interrelated patterns of response concurrent tasks impose on pilots: interleaving and suspending.

1) *Interleaving tasks and monitoring.* In many situations crews must interleave the steps of two (or even more) procedures. For example, most of the pre-takeoff checklist ("down to the line") is run during taxi. The captain must respond to certain items called by the first officer, verifying the status of these items while manually controlling the airplane, keeping track of position in relation to the taxi clearance, and watching for conflicting traffic. The first officer must interleave reading the checklist, verifying items, monitoring the taxi progression, and responding to radio calls.

When the steps of two tasks can be interleaved in a consistent pattern on every flight, the two tasks probably merge into a single procedural memory over time and are likely to be performed quite reliably. However, when the pattern of interleaving must vary from flight to flight, which is often the case, keeping track of the status of each task while interleaving steps is more demanding cognitively. Pilots are especially vulnerable to error if a task step unexpectedly requires an unusual amount of attention.

<u>Summary of ASRS incident report #289346</u>: A first officer executing the pre-takeoff checklist during taxi was interrupted by an unexpected warning signal (a thrust reverser light). Troubleshooting and resolving the problem took a few moments, during which time the ground controller continued to issue traffic sequencing instructions. The first officer monitored the taxi progress and switched radio frequencies to the tower frequency. When the captain prompted him to resume the checklist, he did so but inadvertently omitted an item (setting the flaps to the take-off position.). When the crew attempted to takeoff the configuration warning horn sounded, and the crew had to abort the takeoff.

The most pervasive form of interleaving tasks involves monitoring. Crews must monitor dozens of systems and activities while actively performing other tasks. FOMs describe monitoring duties in a general way but provide little specific guidance on how frequently to check the status of the various monitored items or how to divide attention between monitoring and other tasks performed concurrently. Recognizing the importance of monitoring as a vital defense against errors and system failures, some airlines have begun to increase emphasis on monitoring (Sumwalt, Thomas, & Dismukes, 2002), however specific training on how to monitor is still lacking. Effective monitoring poses considerable cognitive challenges. Checking for untoward events that rarely occur is a vigilance task, at which humans are notoriously poor. Further, the pilot must remember to periodically interrupt an ongoing task to redirect gaze to the event or item to be monitored.

<u>Summary of ASRS incident report #414686</u>: During taxi a first officer discovered that his earlier calculations of performance data for the planned takeoff runway had been based on the wrong flap setting. In the course of rechecking if the aircraft would be too heavy for takeoff from the particular runway, he failed to adequately monitor the captain, who taxied past the hold short line.

If the ongoing task demands considerable mental resources, it is not possible to perform that task and keep the need to monitor in focal attention simultaneously. Thus the monitoring task must be retrieved periodically from memory back into focal attention. We do not yet know how this is accomplished cognitively, but clearly the process is quite vulnerable to lapses. Research is needed to determine whether pilots can, through practice, develop a skill of automatically interrupting an ongoing task and redirecting gaze to items to be monitored, and if so, what factors determine the reliability of such a skill.

2) *Suspending and deferring tasks.* When some agent interrupts a pilot's ongoing task, the pilot must at least momentarily shift attention to the interrupting agent. For example, the ground controller may initiate a radio call to a crew who is in the midst of running the pre-takeoff checklist. In fact, many interruptions, particularly those involving human communications, are sufficiently salient that shifting attention is involuntary. The pilot must then decide

whether to respond to the interruption and return to the interrupted task later or, conversely, bring the ongoing task to a convenient stopping point before responding to the interruption. In either case the pilot must defer one task and must remember to return to that task later. Also, pilots must sometimes defer tasks because conditions do not permit execution at the normal point in the procedural sequence. For example, the pre-takeoff checklist may call for the auxiliary power unit (APU) to be shut down but the type of takeoff may require its use until a safe altitude has been reached.

For several reasons, pilots, like all individuals, are quite vulnerable to forgetting to perform deferred tasks. Pilots may attempt to monitor for the appropriate time to perform the deferred task, but this increases workload, and monitoring is difficult to maintain. Cockpit operations typically require full attention from pilots who cannot continuously rehearse an intention to perform a deferred task in order to keep it in awareness. Thus the intention must be retrieved from memory when time is available and circumstances are appropriate to perform the deferred task. However, time pressure and task demands may prevent the pilot from deeply encoding in memory the intention to resume the deferred task, thereby reducing the likelihood of retrieval. Retrieval of intentions hinges on the individual noticing cues in the environment that are associated with the stored intention and can trigger retrieval of the intention from memory. This is a rather happenstance process and pilots may be so busy with the tasks of getting the airplane ready for takeoff that they do not notice cues that might trigger retrieval of stored intentions. For example, a crew may rely on normally coming to a physical stop at the hold short line at a runway to trigger them to complete the pre-takeoff checklist (below-the-line items). That cue disappears when the tower controller clears them for immediate takeoff without having to hold short of the runway while the aircraft is still taxiing.

<u>Summary of ASRS incident report #263589</u>: *A crew neglected to set the flaps for takeoff after having deliberately deferred that action due to snow accumulation on the taxiways. Once in line for takeoff they became busy discussing a problem they had encountered earlier with the APU. A sudden and unexpected instruction from Tower placing them next for takeoff triggered the crew to rush to complete a wing contamination inspection and the below-the-line part of the checklist, inadvertently omitting the above-the-line items and, thus, not setting the flaps.*

One of the best ways pilots have discovered to reduce vulnerability to forgetting deferred actions is to create a salient cue to remind them, such as placing a checklist between the throttles. Unfortunately, when interruptions are frequent and pressing, pilots do not have time to create an effective cue for each interrupted task and may forget to resume one or more of them.

Pilots may overestimate the probability of remembering to perform a deferred action if that action is one they always perform, such as setting flaps to takeoff position. However deferring habitually performed actions makes them especially vulnerable to omission because it disrupts the normal sequence of action. Normally, performing the steps of a highly practiced procedure places only small memory demands because executing each step automatically prompts retrieval of the next step from memory. However, when a step must be performed out of the normal sequence, as in the above example, this automatic prompting does not occur. Further, retrieval of the intention to perform the deferred step must compete with other tasks currently held in attention. Thus, in this example, when the time became appropriate to set the flaps, the crew was busy and rushed to take off.

Countermeasures

What measures would reduce the vulnerability of pilots to making errors while attempting to manage concurrent tasks? Little research has been conducted to answer this question. We offer some tentative suggestions, based on our cockpit observations and our laboratory research on prospective memory (remembering to perform intended actions). We hope these suggestions will stimulate discussion by the operational community and research by the scientific community.

1) Inform pilots that they are vulnerable to error even in highly practiced routine tasks when those tasks must be performed concurrently or out of normal sequence. Recognizing warning signs associated with the threat will encourage pilots to manage workload and timing of tasks as much as possible. It will also encourage them to use personal techniques such as creating salient cues to remind them of interrupted and deferred tasks. Air carriers could encourage use of these techniques by collecting and sharing information about their usefulness.

2) Carefully examine the content and timing of procedures and checklists. Identify the most common situations in which procedures must be

interleaved and in which interruptions are frequent. Discuss techniques for managing these situations in classroom training and give pilots opportunities to practice these techniques in simulation training.

3) Design operating procedures to minimize concurrent task demands and interruptions. As much as possible, avoid "floating" procedural items that are performed at varying times within a phase of flight. Instead, tie critical functions to fixed reference points. For example, connecting an important action such as setting the flaps to a consistent trigger such as the end of the After Start checklist will help support its recall. We know of one major airline that is currently overhauling its normal operating procedures to these ends.

4) Set traps, strict decision criteria that must be met at specific points in each phase of flight before proceeding. An airline, for example, might instruct crews to request clearance to taxi only after all necessary paperwork is on board the aircraft and has been used to program the flight management system to set up the intended departure.

5) Provide explicit guidance to crews on the importance of monitoring, what to monitor, and how to monitor.

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Figure 1. Errors associated with concurrent task demands reported to the ASRS. The left and right columns (grey) describe, from top to bottom, the flow of prescribed taxi activities for each of the crew members. The overlaid boxes (white) contain information about the error, the contributing factors, and the resulting outcome for each of selected incident reports.