# COCKPIT INTERRUPTIONS AND DISTRACTIONS: A LINE OBSERVATION STUDY

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## ABSTRACT

Preliminary findings about the scope and nature of concurrent task demands on the flight deck are presented. We begin with a detailed description of the typical operations (flows and checklists) involved in the preflight phase of flight. We amplify these descriptions with observations during scheduled, part 121 flight operations. We find numerous and varied events that interrupt and generally distract pilots from their prescribed duties. To respond to such distractions, pilots are forced to interleave novel activities with habitual, well-practiced sequences of actions. In doing so, they continuously engage in the making of decisions involving adding, shedding, and/or rescheduling actions. Opportunities for errors increase dramatically as distractions continuously threaten to sidetrack even the most meticulous and experienced pilot.

## INTRODUCTION

The very appearance of a modern aircraft cockpit bears testament to the fact that the flight deck is the epitome of a demanding workplace. Sitting in the midst of literally hundreds of displays, lights, and switches, pilots must selectively extract and evaluate pertinent information, carry out a multitude of operations, and coordinate all their activities with those of entities outside the aircraft working to make the same flight happen. As a result, pilots are almost always subject to extraordinary levels of workload. Meeting such heavy work demands implies time-sharing of cognitive resources, as pilots must simultaneously engage in multiple activities.

Interest in the issue of time-sharing began decades ago (e.g., Broadbent, 1958). Since then, a large body of research ranging from basic to applied has been devoted to understanding how multi-tasking is effected. Researchers have looked at the human operator both in a general setting (e.g., Moray, Dessouky, Kijowski, & Adapathya, 1991) and in aviation (e.g., Raby and Wickens, 1994). It is generally assumed that cognitive resources, though limited, are under conscious control and can be directed from task to task as necessary. When faced with the demand to simultaneously perform many activities, the operator must evaluate each activity (e.g., based on urgency and implications for the overall goal), determine its attentional requirements (e.g., based on difficulty and skill-level), and decide on an order of precedence. Mental resources are then devoted to each task, one at a time and for a specific duration, such that partial progress is continuously made on all tasks. A monitoring strategy is used to keep track of the progress made, of changes in priorities, new incoming demands, and the need for changes in attention allocation. This strategy may or may not be explicit; either way, it is vital for successful and efficient juggling of the multiple tasks and for acquiring and maintaining general situation awareness.

The issue of how monitoring strategies are selected and followed is a less well understood aspect of multi-tasking. It has been the focus of much research specifically in aviation and has been variably referred to as attention control (Gopher, 1991), flight workload management (Raby and Wickens, 1991), cockpit task management (Funk, 1991), multiple-task management (Latorella, 1996), and agenda management (Funk and Braune, 1996). Tantamount to the monitoring issue, furthermore, is the fact that the flight deck is rarely ever sterile and devoid of distractions. A large number and variety of external, situational factors continuously interrupt pilots and vie for their attention. The complexity of monitoring multiple tasks, exacerbated by the competition for attention by external factors, makes pilots extremely vulnerable to errors. Ample evidence can be found in ASRS incident and NTSB accident reports (e.g., Dismukes, 1998). In all these cases, a lapse in memory or attention resulted from difficulties in managing attention rather than mental overload due to the sheer number of tasks at hand (see also Dismukes, Loukopoulos, & Jobe, this volume).

## FLOWS AND CHECKLISTS

In an effort to help deal with the always-increasing number of flight deck tasks, pilots are taught to rely on *flows* and *checklists*. These tools determine the time- and event-sequence of tasks in the cockpit. When followed exactly, they prepare the aircraft and its crew

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for the ensuing phase of flight. Flows and checklists are initially designed by the manufacturer to meet technical and performance specifications of the specific aircraft. They may later be modified by the air carrier to suit company and fleet operational demands (Degani and Wiener, 1997).

Every phase of flight has one or more flow-checklist pairs. The first typically directs actions that check the current status of aircraft systems, tests them, and configures them for the next flight phase. It is accomplished by memory. Each pilot has separate flows that covers the cockpit panels and instruments that fall within his or her "area of responsibility" in the cockpit. Flows are executed silently during the relevant flight phase, at a time deemed optimal by each pilot. The checklist, on the other hand, is a subset of the flow and contains only the "killer" action items (so called to reflect their critical nature). Checklists are called for by the captain (or Pilot Flying when in the air). They are most commonly read off a laminated checklist card on board the flight deck by the first officer (or Pilot Not Flying when in the air), and are complete when so pronounced ("Checklist complete").

Flows and checklists enable pilots to form associations among tasks: e.g., completion of a flight controls check during taxi triggers a check for the flaps setting which, in turn, triggers checking of the autobrake setting. Through training and repeated use, such associations solidify into habitual, automatic action sequences that can theoretically be relied upon repeatedly without failure provided they are used in sufficiently similar, linear and predictable situations. The habitual element, however, does not serve as well in the dynamic situation of modern day flight operations. Due to the tempo and density of these operations, the flight deck is fraught with interruptions and distractions. Such events interfere with habit, and force pilots to continuously assess and rearrange the sequences they are so well trained to execute. More specifically, interruptions and distractions create the demand to suspend ongoing activities, defer planned actions, and remember to resume suspended actions and/or execute intentions in the future. In doing so, they constantly threaten to sidetrack pilots and make them vulnerable to a variety of potential errors.

It is our goal to better understand and describe the fluid and complex nature of flight deck tasks, and specifically how the operational environment affects them. Incident and accident reports discuss pilot error but largely neglect the underlying causes. Our aim is to identify the causes inherent both in the design of flight deck tasks and their sequence, as well as in the non-linearity of the environment. This analysis will allow us to make recommendations for improvements in both training and procedure design arenas.

## STUDY

We have chosen to study concurrent task issues by collecting observations from the cockpit jumpseat during scheduled revenue flights. To date, 20 flight segments have been observed. The work described is still in progress. All observations were conducted on the B737 aircraft (-300, –500, and -700 variants) of a single air carrier. Flight duration ranged from 1 to 4 hours. A single jumpseat observer (L.D.L) took hand-written notes and used a stopwatch for time-stamping key events. Data were collected during the entire flight and both Captain (CA) and First Officer (FO) were observed. In the current analysis we use the preflight phase to exemplify our methodology and what can be learnt from it. The current observations are all specific to one air carrier and aircraft type; later we plan to examine other carriers and aircraft fleets and extend the analysis to all phases of flight.

Although line operations are highly standardized and normally follow a well-defined script, the fine structure of the sequence of events varies a fair amount from one flight to the next. Obviously, it is not possible to design flows and checklists that accurately predict such variations and are therefore optimal for all flights. Yet, pilots are consistently successful in juggling their high workload together with the added variations. This study focuses on flows and checklists, how they are affected by such variations, and how pilots use them and/or modify them on the line to meet operational demands. Documenting and understanding deviations from trained procedures will help reveal system deficiencies and may suggest possible solutions.

### Preflight

In the preflight phase, the crew "receiving" the aircraft conducts a series of inspections to establish the aircraft's overall condition and configure its systems. This includes both interior and exterior safety inspections, and culminates in a preflight flow of more than 50 items, followed by a checklist of 13 items. In theory, a flow is conducted independently by each pilot, at an opportune time devoid of distractions. Figure 1 depicts the spatial layout of the cockpit panels on the B737 flight deck. Dark shaded areas represent the CA's "areas of responsibility." Light shaded areas represent the FO's "areas of responsibility." Two lines (black for the CA, grey for the FO) mark the sequence of actions required to complete the preflight flow on a B737-300. The beginning of each line is indicated by a circle and its end by an arrowhead. So, for example, the CA's flow at the observed carrier begins with the gear handle on the Center Instrument panel, proceeds up to the Forward Overhead panel, on to the Mode Control Panel, etc. The FO's flow begins at the Aft Overhead panel, proceeds down to the Forward Electronic panel, on to the Forward Overhead panel, etc. Asterisks mark those items that also appear in the ensuing checklist. Were pilots to operate in a sterile environment, one devoid of interruptions and other distractions, it should be possible to observe their hands and eyes follow this sequence exactly.

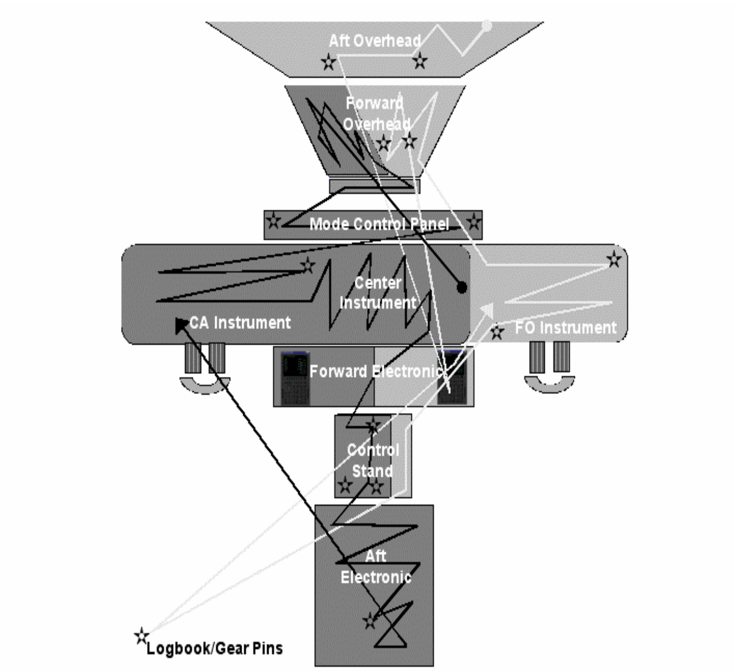


*Figure 1. Pilots' preflight flow on the B737-300.*

Design characteristics. The preflight flow loosely follows the spatial configuration of panels and instruments in the cockpit. To the extent possible, each pilot examines panels from top to bottom and from left to right and does so without overlaps and loops. However, note that the Aft Overhead panel is traversed right to left, but the Forward Overhead and Instrument panels are traversed left to right. Also, a loop occurs in the transition from Aft Overhead down to Forward Electronic and back up to Forward Overhead panels. Such exceptions to the general convention of spatial task sequence can be a source of confusion and errors.

The entire flow consists of more than 50 action items. A given action item, however, may "fold" multiple actions within itself. For example, the action item "Mode Control Panel" involves 10 separate actions: set both course arrows to the departure heading, the IAS/Mach selector to V2, the altitude selector to the first cleared altitude, the bank delimiter to 35 degrees, both flight directors on with the appropriate "master" on, and the heading selector to the runway heading. Other Flow action items include optional system checks. For example, the item "Flight Control Panel" at the specific airline involves 6 actions to check for switch positions and light indications and an optional check for the standby system if this is the first flight of the day. Such convolutions in a flow can lead to omissions, especially in the face of distractions and time pressure.

An interesting design characteristic involves the Inertial Referencing System (IRS). The system's two units require between 5 and 17 minutes to align themselves after the corresponding selectors have been turned on. Since alignment must be complete before entering data into the Flight Management System (FMS), pilots prefer to start the alignment process as early as possible and not wait until the preflight flow directs them to do so. In fact, most pilots will elect to turn the IRS selectors on as soon as they walk on board and establish electrical power on the aircraft, long before they are ready to take their seats and start their flow. While reaching for the selectors on the Aft Overhead panel, however, they will also continue with the remainder of the items on the same panel. The observed result is that the typical crew today shifts a section of the preflight flow to a point in time earlier than that intended to accommodate a technical demand.

In the effort to be somewhat flexible, flows also contain "floating" items whose completion time is not exactly specified. The most characteristic example is the FMS, a critical system whose complex programming requires considerable time and depends on the availability of pertinent paperwork. According to the flight manual, every effort to perform as much programming as possible at this stage must be made. Actual completion, however, is not checked until the taxi phase. Obviously, programming is a complex activity and requires the pilot to go "head-down." It follows that the more programming accomplished while the aircraft is still stationary, the more cognitive resources are freed up during taxi for crucial monitoring. Yet, pilots are often forced (worse even, often opt) to defer programming the FMS because either the paperwork is not all available during preflight or they anticipate possible taxiway and/or runway changes that may cause unnecessary duplication of their actions.

Finally, some items in the preflight flow require coordination between CA and FO. The FMS, for example, is programmed by one pilot but must be cross-checked by the other before considered complete. This either implies that one pilot interrupt the other pilot to signal completion of the system's set-up and the need for a cross-check, or that the other pilot determine when set up is complete and remember to cross-check at his or her discretion. Under the threat of time pressure and multiple interruptions, such coordination can be at best tricky if not altogether impossible.

Observations. We have described the textbook version of the preflight flow, that is, the flow as it appears in the flight manual and as taught in the classroom. We have also described some potentially error-inducing design characteristics. We now turn to jumpseat observations and what they tell us about environmental factors that may induce errors.

The first observation concerns the large number of flow actions that appear to depend on external factors such as weather and paperwork. We will call such dependencies *uncertainties.* Overall, uncertainties create the need for rescheduling, deferring, and delaying tasks. Figure 2 illustrates the list of all uncertainties we observed so far in this study as well as the time of their occurrence within the flow.


*Figure 2. Uncertainties affecting the preflight flow.*

The exact list of actions in the preflight flow is listed on the left for the CA and the right for the FO. Two arrows, one on each side, indicate the intended sequence of actions from top to bottom. Asterisks again mark those items which later appear on the preflight checklist. Comments in the middle, between the CA's and the FO's flows summarize observed factors of uncertainty and arrows point to the specific flow item they affect. Overall, note that almost every action is linked to an uncertainty factor. For example, the "Fuel System" check depends on the refueling status of the aircraft at the time of check; the aircraft "Exterior Lights'" settings depend on time of day and/or weather; whether this is the first flight of the day determines if additional system checks need to be accomplished; and the "Radar" check depends on alignment of the Inertial Referencing System (IRS). These and all the examples listed in Figure 2 constitute unpredictable elements of the operational environment. Their presence or absence, as well as their effects and implications, are beyond the pilots' control. They are, however, attention-demanding in that they cannot and must not be ignored, and require consideration before a decision is made about how to respond to them.

Another observation involves division of responsibility. Despite the fact that the flow is designed around prescribed areas of responsibility and division of labor, pilots will frequently swap duties and "cover" for one another. The FO will often conduct parts of the CA's flow and vice versa, depending on time constraints and who arrived first at the aircraft. In fact, training enables and encourages such swapping of duties by teaching both pilots the same flow. In real life it is not immediately clear how pilots keep track of who already completed what and how to avoid uncertainty and omissions when duties are swapped.

Paperwork is another integral part of a flight that may cause considerable uncertainty. Specifically, settings on the MCP depend on information in the Predeparture Clearance (PDC) whose availability at the time of preflight varies greatly. FMS settings also require information found on the Flight Plan, the PDC, and the Weight & Balance sheet. The availability of all these forms varies from flight to flight. Critical paperwork often arrives only when the aircraft is ready for push-back, necessitating FMC updates during taxi. The haphazard arrival of paperwork on the line is poorly, if at all, captured in simulator training.

During preflight, cabin crew, gate agents, dispatchers, ground safety, ramp control, ground control, refuelers and maintainers are all working towards the same goal of getting this flight off the ground. Their collaboration requires a high degree of communication, both among themselves and with the cockpit crew. All communications and information exchanges, however, result in interrupting and distracting the pilots who must attend to such exchanges if they want to remain aware of all progress and/or problems regarding the flight in preparation. We call such events *intrusions* because they are unpredictable both in nature and timing, demand immediate attention, and hence intrude on the cockpit crews' responsibilities.

To help better appreciate the interference caused by intrusions, Figure 3 sketches one possible scenario of the time evolution of the preflight flow. We base this example on observations we compiled in our study. Similar to the previous figure, the list of actions in the preflight flow is listed on the left for the CA and the right for the FO. Two lines (left for the CA, right for the FO) indicate the time sequence of events as each pilot proceeds from top to bottom along the preflight flow; each line begins at the circle and ends with an arrowhead. "Bubbles" in the middle reflect the sources of observed intrusions. Note that the lines now not only follow the flow sequence but also often point to intrusions. We mask the particular flow items with x's to signify that the exact point of occurrence of the intrusion is less relevant than the fact that it interferes with execution of any one action during the preflight flow. In the case shown here, there are three major intrusions: a passenger issue noted by the gate agent, and a paperwork issue and a cabin discrepancy, both noted by the cabin crew.

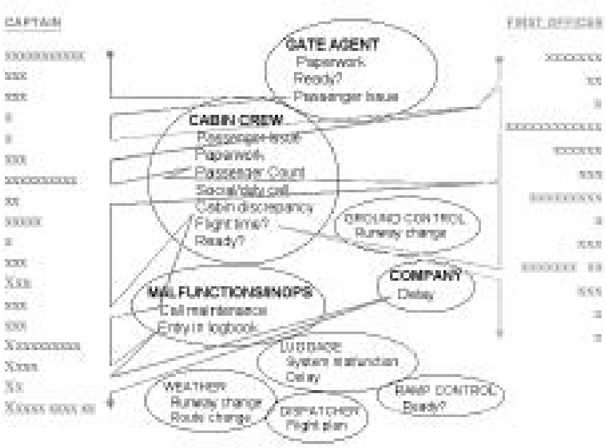


*Figure 3. Example of a preflight flow based on intrusions observed during real-life operations.*

To respond to the three intrusions, pilots interleave them with their prescribed duties. For example, not too long after the CA starts the preflight flow the gate agent brings a passenger issue to the crew's attention. The CA is forced to momentarily suspend the flow, listen to the nature of the issue, determine its relevance and urgency, and decide what action to take. After determining that the passenger issue is not as important as the specific flow actions that were interrupted, the CA continues on with the next couple of items in the flow, and only then suspends his or her activities to coordinate with the FO regarding the passenger issue. Upon return to the flow, the CA is again interrupted by a flight attendant delivering the final passenger count. This momentary intrusion requires the CA to simply acknowledge receipt of the paperwork and hand it to the FO before returning to the flow. The last intrusion occurs when a flight attendant reports a cabin seat discrepancy (malfunction). This interruption is more demanding: the CA must determine its implications, notify the maintenance crew, ensure an entry in the logbook, and assure some corrective action is taken prior to pushback. Just before completing the preflight flow, the CA assesses the overall effects of these intrusions, and notifies the company of a new pushback time.

What becomes evident from this example is the infinite number of instances where the pilot has to divert attention to intrusions while executing a habitual procedure. Compare the straight line representing the flow for each pilot in Figure 2 with the jagged line representing the same flow in Figure 3. Notice how convoluted the flow line appears in this hypothetical scenario. Intrusions force pilots to interleave novel, unpredictable tasks (responses on a case-by-case basis) with well-practiced, habitual sequences (flows). To succeed, pilots continuously form and defer intentions and remember to resume suspended activities, thus allowing themselves to become vulnerable to errors of forgetting or becoming preoccupied with one task at the expense of another.

Errors. Preflight errors resulting from uncertainties and intrusions are frequently cited as contributing or causal factors in aviation incidents and accidents. Line-Oriented Safety Audit (LOSA) reports indicate that 23% of errors and 38% of threats occur before the aircraft leaves the ground (Helmreich, Wilhelm, Klinect, & Merritt, in press). The outcomes of such errors vary greatly. For example, neglecting to set the airspeed bugs should be noticed and can be rectified during the taxi checklist with no consequences. Neglecting to turn the window heat on, however, may cause a forced delay if discovered during taxi, as it requires 10 minutes to become operational. Some errors can have fatal consequences. An erroneous trim setting was the cause for the crash of a DC-8 after a failed takeoff (NTSB Report # NYC91FA086).

## DISCUSSION

We have discussed one phase of flight and illustrated its complexity not only in terms of workload but, more critically, in terms of its demands for concurrent task management. Flows and checklists are excellent tools for helping pilots deal with the large number of required tasks. They allow pilots to fall back on habit and mnemonics and are reliable in most normal situations. When examined in real-time, on real-life flights, however, existing flows prove insufficient for dealing with operational demands and cannot guarantee correct, efficient, and safe performance. Perhaps the most difficult demands are those due to uncertainties and intrusions: events beyond the pilots' control that must be attended to and hence generate the need for rescheduling, adding, shedding, or deferring tasks. Flows and checklists cannot possibly anticipate all operational demands and are thus not designed to accommodate them.

We believe that uncertainties, intrusions, and general distractions can quickly sidetrack any pilot and lead to potentially disastrous mistakes. All pilots are vulnerable to error, even if they (and we) would like to believe otherwise. So insidious are the effects of distractions that pilots will express an experience of amazement when an error is made: *"… I have flown this airplane for 10 years and never set this (pressurization control) wrong. I am unsure how it happened except that possibly I was interrupted during my preflight check …" (ASRS #398017).* The question, then, is how to best equip pilots with tools to minimize vulnerability to errors. In the face of operational demands that surpass the limitations of any operator and his or her tools, we must consider the pragmatic demands of the work environment. We must also examine parallel issues such as the effect of varying levels of automation, and how demands vary across airlines, fleets, and routes. Our observations can provide invaluable input to training modules designed to increase awareness of attention management issues. Finally, given that attention management may be a trainable skill (Gopher, 1991), it may be time to consider including it in pilots' curricula using examples from real-life operations.

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