When Does the MCDU Interface Work Well?

Lessons Learned for the Design of New Flightdeck User-Interfaces

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Abstract

The Multi-function Control and Display Unit (MCDU) has been identified as a source of issues pilots have transitioning to glass cockpits. Several aircraft manufacturers and avionics vendors have committed to replace the MCDU with graphical user-interfaces in the next generation of commercial aircraft.

A cognitive task analysis of pilot-MCDU interaction, described in this paper, has identified that pilot failure to complete mission tasks using the MCDU is not a sole consequence of the physical dimensions or layout of the device. Instead, the MCDU interface works adequately when a given pilot task: (1) is supported directly by a function provided by the automation, and (2) the access of MCDU pages, and format and entry of data, are prompted by labels and other visual cues (and not by memorized actions sequences). Pilot tasks not supported directly by automation, and/or pilots tasks that rely on memorized action sequences are difficult to learn and likely not to be used effectively in the field.

Introduction

The Multi-function Control and Display Unit (MCDU), first introduced to commercial aircraft in the generation of aircraft designed during the 1970's (e.g. A300, A310, B757, B767), serves as a passive user-interface for the Flight Management System (FMS). The MCDU has come under much criticism as one of the primary sources of difficulties in using the Flight Management System (FMS). See BASI, (1999); Sarter, Woods & Billings (1997); Hutchins, (1994); Dodd, Eldredge & Mangold (1992), Mann & Morrison (1986). Several aircraft manufacturers, avionics vendors, and researchers are exploring alternatives to the MCDU user-interface for future aircraft (Marrenbach & Kraiss, 2000; Jacobsen, Chen, Widemann, 1999, Riley, 1998; Abbott, 1997; Hutchins, 1994).

The benchmark for human-computer usability is modern office automation, such as the Mac OS and Microsoft Office applications. The user-interfaces of these applications exhibit two general characteristics. First, they provide users with a rich set of functions to directly aid in completing tasks (e.g. creating graphs from spreadsheet data). Second,

they enable a user with the appropriate domain knowledge (e.g. statistics) and knowledge of the user-interface conventions (e.g. Windows point and click) to command the automation to perform complex tasks by guiding user interaction through visual cues. Mission tasks that are: (1) not directly supported by the automation, and (2) pilot actions that must be memorized due to the absence of visual cues, increase the training footprint, and are the source of excessive cognitive workload, and increased probability of errors.

A cognitive usability analysis of pilot-automation interaction with the MCDU found that:

- the MCDU serves as an adequate user-interface when the *pilot task is directly supported by features* of the Flight Management System (FMS) that are accessed via the MCDU. In contrast, the MCDU is a clumsy user-interface when a pilot task requires significant reformulation of the task into sub-tasks and/or alternate representations in order to use the automation

- the MCDU serves as an adequate user-interface when the access of the correct MCDU page, and the format and insertion of data *are prompted by labels and other visual prompts* (not memorized action sequences). This is especially important for automation features that are used infrequently. In contrast, the MCDU is a clumsy user-interface when the access of the correct MCDU page, and the format and insertion of data rely exclusively on memorized action sequences to complete the task (no visual cues).

This analysis indicates that the problems described in the literature on the operation of the MCDU are not only a result of physical size or layout, but a consequence of the way tasks are automated and an over-reliance on memorized action cues. New graphical user-interfaces proposed for the flightdeck may "paint themselves into the same corner" without: (1) careful design of the pilot tasks to complete the missions that are supported by the automation, and (2) sufficient labels, prompts, and meaningful feedback messages to enable the pilot to perform the task.

This paper describes a model of pilot-automation interaction and the characteristics of the user-interface that yield robust pilot-automation interactions. A task involving the use of the MCDU is described to illustrate inherent weaknesses and strengths of the MCDU design. The final section

of the paper discusses the application of these ideas in the design of new flightdeck user-interfaces.

This research was conducted in collaboration with Boeing – Human Factors, NASA, and Honeywell, and reflects the results of the research to date.

Pilot Interaction With The MCDU

For the purpose of analyzing pilot-automation interaction, a model of pilot's cognition was created by combining the cognitive models created for studying aviation pilot-automation interaction by Palmer, Hutchins, Ritter & van-Cleemput (1992), and Polson, Irving, & Irving (1995). The model also draws on the Cognitive Walkthrough of Wharton, Rieman, Lewis and Polson (1994), and Polson & Smith (2000). This model is known as the RAFIV model (**R**eformulate, **A**ccess, **F**ormat, **I**nsert, and **V**erify & Monitor).

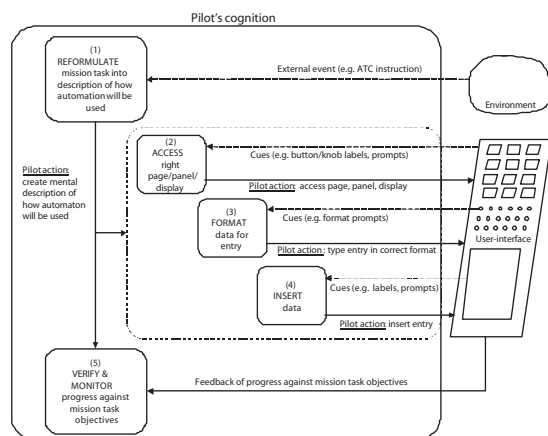When interacting with the automation, pilot's cognition may be described by five discrete steps (Figure 1).

*Figure 1. Pilot interaction with the automation is described by five steps: **R**eformulate, **A**ccess, **F**ormat, **I**nsert, and **V**erify and Mon itor.*

(1) **Reformulate** *the mission tasks into sets of data that can be communicated to the automation*. Pilots create a mental description of the how the automation will be used to perform a given task. For example an ATC clearance must be converted into a set of data that can be entered into the automation (Palmer, Hutchins, Ritter & van Cleemput; 1992).

Once a description on how to use the automation has been defined, the pilot must perform actions to transfer the description to the automation via a sequence of actions. These actions have been divided into three steps by Polson, Irving, Irving (1995).

(2) **Access** *the right user-interface:* The pilot must access the right page (e.g. hierarchy of MCDU pages), panel (e.g. Mode Control Panel), or display (e.g. multi-function synoptic displays). The access step identifies the actions that must be taken on the user-interface to display the fields for data entry. For example, on the

Pilot Task: ATC: "lateral route offset 6 miles left"

Cognitive step	*User-interface cues, labels, and prompts (Strength)*	*Knowledge required from long-term memory (Weakness)*
How automation used: Offset Active Route 1 by 6 miles to the left	Term "route" triggers use of the MCDU RTE page	Pilot must remember: - offset is manipulation of the route (not legs) - offset applies only to certain portions of the route (e.g. not on published STAR, etc…)
Access: MCDU Route page	Mode key labeled RTE	None
Format: <side L or R><distance in nautical miles>	LS 6R labeled "OFFSET" Field is dashed ("----") (**No indication of format**)	Pilot must remember format <side L or R><distance>. Also pilot must remember distance is limited to 99nm.
Insert: (1) LS 6R, (2) Execute	LS 6R labeled "OFFSET"	None
Verify & monitor: 6 miles to the left of the active route. Avoids the reason for the offset (weather or traffic)	ND provides good information to confirm the entry, and monitor the progress.	Pilot must remember that offset applies only to certain portions of the route (e.g. not on published STAR, etc…)

Table 1. Analysis for the "lateral route offset" task. Items that must be memorized are shown in column 3.

Airbus MCDU, revisions to the vertical flightplan are performed on the Vertical Revision page which is accessed by selecting a right line select key on the F-PLN page when nothing is in the scratchpad.

(3) **Format** *Data for Entry:* Pilots must format the data to be entered into the automation (e.g. MCDU scratchpad typing). For example entries of speed and altitude constraints must be entered in the format <speed> / <altitude>. Note: The Format step is more specific than the Designate subtask of the Polson, Irving, and Irving (1995) model. Palmer, Hutchins, Ritter & vanCleemput. (1992) describe the complex transformations of the data must occur between ATC and data entry.

(4) **Insert** *Data:* Once the data is formatted the pilots takes actions to insert the data in the correct location. For example an altitude clearance must be dialed into the altitude window of the MCP, or an entry in the MCDU scratchpad is inserted by selecting the line select key adjacent to the MCDU page field for the entry.

Once the entry has been made, the pilot must verify and monitor the progress of the aircraft trajectory against the goals and objectives of the pilot task.

(5) **Verify and Monitor:** The pilot must verify that the automation: (1) has accepted the pilot entry, (2) is performing the intended task within the envelope of acceptable performance, and (3) is satisfying the mission

objectives (Fennell, 2002). This step involves scan and use of data from throughout the flightdeck.

Optimizing Pilot-Automation Interaction

Each of the steps in the model of pilot cognition described above is performed by the pilot by either *recalling* the appropriate action from long-term memory or by *recognizing* the appropriate action from some cue in the environment (e.g. button label).

Recognition is far more robust and quicker than recall. First, pilots, like all humans, tend to fail to remember items that are used infrequently (Javaux, 2000). Second, a human pilot's ability to recall is subject to the inherent workload limits of human attention, the ability to deal with interruptions, and the existence of appropriately contextualized knowledge in long-term memory. Third, the costs, and time of building and maintaining correct cognitive knowledge structures for accurate and timely recall of memorized action sequences, drives up the costs of pilot training. The volume of memorized action sequences required to use the FMS is a major source of the "drinking from a fire-hose" effect described by pilots on transitioning to glass cockpits (BASI, 1999).

The user-interface provides the primary mechanism for a recognition-based operation of the automation. Recognition-based operation is supported by providing functions that directly carry out pilot's tasks in a way that minimizes, or eliminates, the reformulation cognitive step in the RAFIV model (Figure 1). Recognition-based operation is also supported by providing labels, prompts and meaningful feedback of pilot actions such that the user-interface guides the pilot to access the correct page (or display), enter the correct data in the appropriate format, and insert the data in correct field. This type of information is illustrated in Figure 1 for each of the five steps.

Example RAFIV Analysis: Lateral Route Offset

The RAFIV steps for execution of the lateral route offset task on B777 are summarized in Table 1 (B777 FMS Pilots Guide, page 3.4-28). For each RAFIV step, column 2 describes the visual cues provided by the MCDU to support the pilot in executing the task. These are strengths of the MCDU user-interface. Column 3 identifies memorized knowledge required to complete the task. This knowledge must be trained and then recalled by the pilot to complete the task. These are weaknesses of the design of the MCDU user-interface.
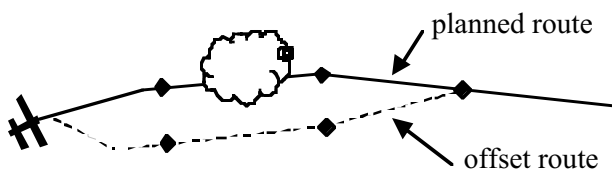

Figure 2. Entry of Lateral Offset Route six mile right

Air Traffic Control issues (or approves a request for) a lateral offset to the right or left of the path to enable an airplane to fly around a weather cell that lies directly on the planned route or to avoid traffic. The lateral offset is considered a temporary deviation from the planned route. Once the aircraft has passed the disturbance, the aircraft returns to the planned route (Figure 2).

The first cognitive step is to reformulate the ATC instruction to fly a lateral offset of the original route into an instruction for the automation. The MCDU/FMS *directly* supports the *complete* task via the Lateral Offset Route function that enables the pilot to establish a parallel lateral offset path to the left to right of the original route. Table 1 summarizes the absence of visual cues that the automation provides to support the pilot's use of this feature. The existence of this feature must be memorized as one of the manipulations that can be performed on the ROUTE representation of the flightplan (not the LEGS representation). Furthermore, there are several complicated rules that define which portions of the route the automation will build an offset route. For example, a lateral route will not be constructed for SIDS or STARS. These elements of a flightplan are not explicitly identified on flightdeck displays.

Once the description of how to instruct the automation has been determined, the second cognitive step is to access the correct page. The term "offset the lateral **route**" used in the reformulation step cues the pilot to access the RTE page using the RTE mode key. A field labeled "OFFSET" with dashed lines indicating availability of the feature (Figure 3).

Figure 3. MCDU RTE page for activation of the Lateral Route Offset task. Access, format, and insert actions are identified.

The next cognitive step is to format the entry. The MCDU page offers no help in formatting the entry. The pilot must recall from memory that the format is <side L or R><distance in nm.>. This format must be trained and then recalled in the "heat of battle." Entry of the values in reverse order or the use of other symbols for left or right, results in an error message "INVALID ENTRY." If the format is not memorized, the absence of a visual cue is a single point failure and will result in the failure to complete the task.

Once the entry has been typed into the scratchpad, the LS key adjacent the field labeled "OFFSET" must be selected. This is an effective user-interface design.

The final cognitive step in this example, is to verify the entry and monitor the progress towards the desired objective. The ND provides good feedback with a white dashed line of the proposed offset that turns magenta once confirmed by the Execute key. Without an overlay of weather (from weather radar) or traffic (DAS-B/TCAS) on the ND, the pilot cannot ensure adequate clearance. As discussed above, the automation includes several rules associated with the type of legs and procedures that can be offset. Since current ND's fail to identify these legs, the pilot must recall these memorized rules. This may be difficult to do for a task that is performed infrequently.

When The MCDU Works Well
(And When It Does Not)

The implications of the RAFIV analysis are that the functions provided by the automation and the visual cues guiding pilot interaction with the user-interface are more important that the size and layout of the MCDU. These considerations are discussed for each of the RAFIV steps below.

Reformulating pilot goal into description of how to use the automation (Step 1)

The MCDU/FMS is filled with features that provide the pilot with automation to perform mission tasks (Table 2). The pilot may select a button (e.g. DESCEND NOW on the LS 6R on the B777 VNAV-DES page), or enter data (e.g. waypoint ICAO identifier for DIR TO) to command the automation to perform these tasks.

There are also a set of mission tasks that are not supported by the MCDU/FMS (Table 2). For example, the instruction to descend to cross a waypoint at a specified altitude and speed is not performed by the automation. Note: entry of a speed and altitude constraint at the specified waypoint in the flightplan does not guarantee that the aircraft will be commanded on an appropriate trajectory.

When the MCDU/FMS does not directly support the task the pilot must reformulate the task into alternative tasks or a sequence of sub-tasks that the automation can perform (Riley, 1998; Palmer, Hutchins, Ritter & Van Cleemput, 1992). This behavior relies on the use of memorized actions. It is time consuming and attention demanding, and therefore subject to failure.

Pilot tasks that require significant reformulation of the task to match the internal representation of the automation, or because the automation does not directly support the task, result in non-robust pilot-automation interaction. This is compounded even further when the task is performed infrequently. A graphical user-interface on automation that does not provide functionality to support the mission tasks will not eliminate the reformulation cognitive step.

Accessing the page (Step 2)

Once the description of how to use the automation has been formulated, the pilot must access the correct MCDU page. Access actions that must be trained and recalled are subject to errors, while those actions that are cued by visual stimuli are robust.

Access is a serious problem even for applications with well designed graphical user interfaces such as Microsoft Office. Selecting a menu item or clicking on a tool bar icon in the in a Windows environment requires some use of recall to remember that function exists and where to locate the icon.. Remembering how to find the correct menu item or identify the icon can be very difficult for novel or infrequently performed tasks.

Tasks Supported by the MCDU/FMS	Tasks **not** Supported by the MCDU/FMS
- Alignment of ADIRU Position - Flightplan/Route Planning - Aircraft Performance Computations - Direct To - Holding Patterns - Lateral Route Offset - Missed Approach/Go Around - Descend Direct - Descend Now	- Climb through intermediate altitude constraint - Descend to crossing restriction - Change departure/arrival runway - Adjust climb speeds to achieve desired climb gradient - Crossing radial with altitude restriction

Table 2. Sample of tasks supported and <u>not supported</u> *by the MCDU/FMS*

The MCDU provides several visual cues to aid this action. Most prominent are the Mode keys that directly access MCDU pages and the prompts at LS keys for moving from page to page.

A review of the Airbus and Boeing MCDU Mode keys reveals two types Mode keys. One class of Mode keys is associated with mission tasks (e.g. Hold or Direct To). The other class of Mode keys is used to access symbolic representations of objects or information (e.g. Flightplan legs, or computed performance values). Tasks that require manipulation of symbolic representations are not directly related to the environment must be trained and recalled at the time of execution. For example, all tasks associated with the modification of the planned route require MCDU actions to manipulate the text-based list of flightplan waypoints. These manipulations, that have nothing to do with aviating, navigating, or communicating, constitute a large portion of glass cockpit transition training.

Format (Step 3) and Insert (Step 4)

Once the page has been accessed, the pilot must format the entry and insert it. Some MCDU fields provide excellent visual indications for format and insertion (e.g. FROM/TO, COST INDEX, ..etc) Other MCDU fields fail to provide useful format information. Most of these are associated with multiple entries with abbreviations such as the lateral Route Offset described above.

The best user-interface design for format and insert is the use of dialog boxes and pull-down menus that allow selection from a list of options without any typing. Both Airbus and Boeing MCDUs use "pull-down menus" successfully for stringing flighplan Runways, SIDS, STARs, and Approaches. Also the ability to select waypoints from the flightplan for insertion for Direct To is accurate, fast and eliminates errors introduced by typing. Abbott (1997) describes the application of dialog boxes and wizards for formatting and insertion of data for the MCDU.

Verify and Monitor (Step 5)

The question of feedback on the flightdeck is a much larger issue than the MCDU as most mission progress feedback is derived from the ND and PFD. Some functions accessed by the MCDU can be verified and monitored on the MCDU (e.g. radio tuning). Most flightplan and aircraft performance entries must be verified and monitored on the ND and PFD. The ND provides strong feedback for the lateral flightplan. Information for the vertical axis is available on the ND but requires some inference to build a complete mental model. For example, the display feedback of the vertical intercept of the optimum descent path provides no guidance as how the descent will be achieved and whether airbrakes or additional speed will be required at some future point.

Conclusions

The RAFIV cognitive task analysis of pilot-MCDU interaction identified that pilot failure to complete mission tasks using the MCDU is <u>not</u> a consequence of the physical dimensions or layout of the device. The MCDU interface works adequately when the pilot task is supported directly and completely by a feature of the automation that is accessed through the MCDU, and when the access of the MCDU page and format and entry of data are prompted by labels and other visual cues.

In contrast, pilots failure to complete mission tasks using the MCDU can be directly attributed to a significant reformulation of mission tasks that is required to use features of the automation, and/or an over-reliance on memorized action sequences to access the correct pages, and format and insert data.

The design of future flightdeck user-interfaces should be driven by the following two principles:

- Establish the mission tasks and tasks/sub-tasks that are supported by automation (and those that are not).
- Add sufficient labels, prompts, and meaningful feedback to enable the pilot to perform the task for each of the RAFIV cognitive steps.

Graphical user-interfaces on the flighdeck do not inherently solve problems using automation unless they address the issues of Reformulation, Access, Format, Insert and Verify & monitor. The appropriate use of graphical user-interfaces can solve Reformulate and Verify steps by providing the means for visual representations of the environ-

ment (e.g. graphical flightplans) that can be directly manipulated to complete a mission task. These visual representations must reflect the mission task to avoid a large reformulation and verify steps. Graphical user-interfaces can also solve problems in the Access, Format, and Insert steps through utilization of pull-down menus, dialog boxes, and wizards.

The RAFIV analysis suggests that the success of any new user interfaces for the flightdeck lies in the abilities of the designers *to understand the mission tasks and provide automation to support the pilot in executing these tasks.* Once this has been accomplished, the *design of the user-interface should include mechanisms to address Access, Format,* and *Insert* issues.

Several techniques have been developed to perform this analysis. The analysis of recall and recognition for each RAFIV step is derived from the Cognitive Walkthrough for office automation (Wharton, Rieman, Lewis, & Polson, 1994). The RAFIV analysis, described in this paper, is tailored specifically to support analysis of flightdeck systems.

Acknowledgements

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