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), introduced to the commercial aircraft flightdeck in the 1970's, has been identified as a source of the 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 identified the failure to complete mission tasks using the MCDU is not a consequence of the physical dimensions or layout of the device. Instead, issues with operation of the MCDU can be attributed to: (a) significant reformulation of mission tasks in order to use features of the automation, and (b) over-reliance on memory to access the correct pages, and format and insert data. This paper describes this analysis with an example, and discusses design guidelines for MCDUs or new graphical displays.

Keywords Cognitive task analysis, MCDU, graphical user-interfaces, RAFI analysis, flightdeck user-interface.

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); Dornhein, M. (1996); 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; Faerber, Vogl, Hartley, 2000; Jacobsen, Chen, Widemann, 1999, Riley, 1998; Abbott, 1997; Hutchins, 1994).

The goal of this paper is to describe the characteristics that maximize the usability of user-interfaces on the modern flightdeck. The benchmark for human-computer usability is modern office automation that is represented by the Mac OS and Microsoft Office applications. The user-interfaces of these applications exhibit two features. First, they provide knowledge workers with a rich set of functions to aid the worker in completing their 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 a complex task. This command is issued without converting the task to an alternative representation made up of several non-statistic sub-tasks, or by looking-up steps in an automation reference manual. An alternative way to think about the user-interface and the automation is that they can be operated through "exploration" of the user-interface (Wharton, Lewis, Rieman, & Polson, 1994; Kitajima & Polson, 1997).

A cognitive usability analysis of pilot-automation interaction with the MCDU, developed based on the analysis of flow of information in the cockpit (Palmer, Hutchins, Ritter, vanCleemput, 1992), and the Cognitive Walkthrough (Wharton, et.al., 1994; Polson & Smith, 1999), identified the source of difficulty in using the automation:

(1) MCDU/FMS automation features do not adequately support *all* the mission tasks. A significant number of mission tasks require *reformulation of the mission tasks*, by the pilot, in order to use the automation

(2) Operation of the MCDU/FMS requires an *over reliance on memorized actions sequences* (i.e. the user-interface mode keys and page displays fail to cue the pilot with sufficient labels, prompts, and meaningful feedback messages to enable the pilot to perform the task without significant use of memorized actions)

The reformulation of tasks and the reliance on memorized action sequences makes the operation of the automation difficult to train, increases workload, and is error prone.

This analysis indicates that the problems described in the literature on the operation of the MCDU are not a result of the physical display 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 mission 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 the 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 and future work.

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

PILOT INTERACTION WITH THE MCDU

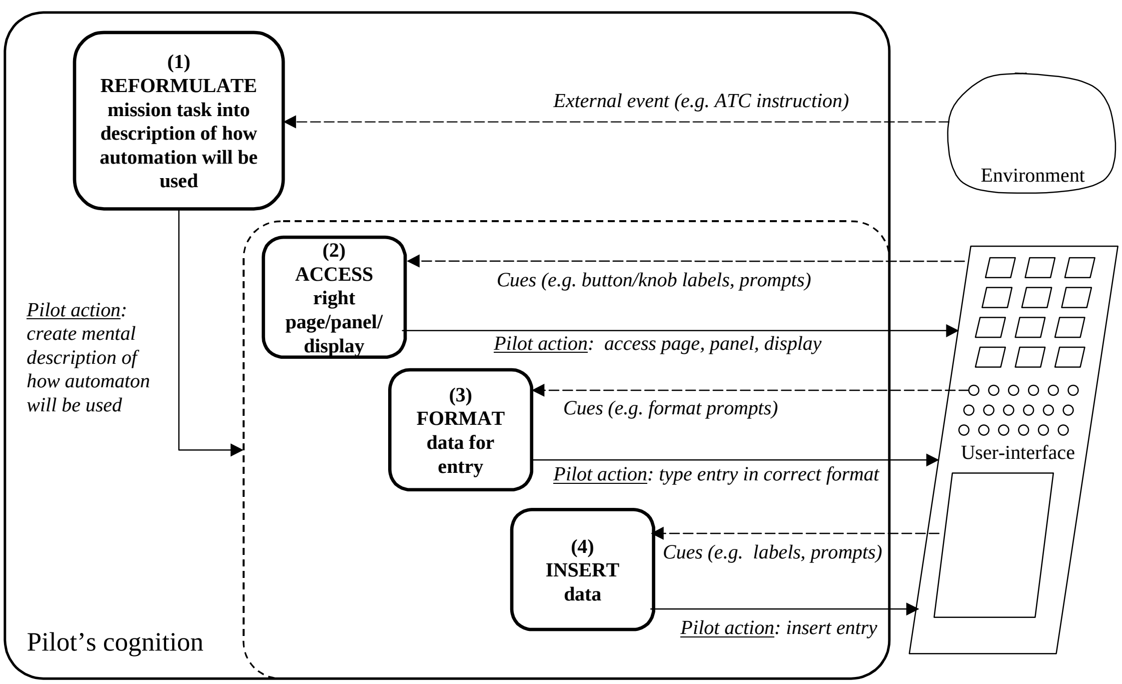
For the purpose of analyzing pilot-automation interaction, a model of pilot's cognition was created by combining the cognitive models created for studying aviation pilot-automation interaction by Palmer, Hutchins, Ritter & vanCleemput (1992), Polson, Irving, & Irving (1995), and Kitajima & Polson (1997). 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 RAFI model (Reformulate, Access, Format, Insert).

Pilot's cognition is broken-down into four discrete steps (Figure 2).

(1) ***Reformulate*** *the mission tasks into sets of data that can 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 & vanCleemput; 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* Once a description on how to use the automation has been defined, 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 (e.g.



Model of pilot cognition is represented by fours steps: Reformulate task, Access display, Forma data, and Insert data. RAFI model is used for cognitive usability analysis.

Figure 2

Vertical Revision page on the Airbus) or orient pilots attention to the correct input device (e.g. Mode Control Panel LNAV button).

(3) ***Format** Data for Entry:* Pilots first have to formulate the information to be entered into the displayed page, altitude widow, dialog box, etc. Then, pilots must format and enter the data (e.g. MCDU scratchpad typing). This step is a generalized version of 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) ***Inser**t 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.

Optimizing Pilot-Automation Interaction

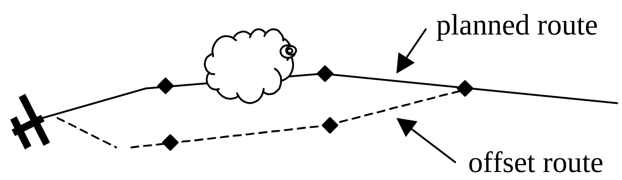
Each of the steps in the model of pilot cognition described above is performed by the pilot by either *recalling* the appropriate action from long-term memory or by *recognizing* the appropriate action from some cue in the environment (e.g. button label).

Recognition is far more robust and quicker than recall. For example, the obligatory use of checklists to avoid omission of critical steps in complex procedures (Boorman, 2001). 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 and ability to deal with interruptions. Finally, the costs, time, and effort of building and maintaining correct cognitive knowledge structures for accurate and timely recall drives up the costs of pilot training and 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 RAFI model (Figure 1). It is also necessary to provide labels, prompts and meaningful feedback of pilot actions, 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 four steps.

Example: Lateral Route Offset (B777)

Air Traffic Control issues or approves 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).



Entry of Lateral Offset Route six mile right

Figure 2

The four cognitive steps for execution of this task on B777 are summarized in Figure 3-a (B777 FMS Pilots Guide, page 3.4-28). For each step column 2 describes the visual cues provided by the MCDU to support the pilot in executing the task. These are strengths of the design. Column 3 identifies memorized knowledge required to complete the task that must be trained and then recalled by the pilot to complete the task. These are weaknesses of the design.

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 this 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. Figure 3-a summarizes the absence of visual cues that the automation provides to support 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 legs of the flightplan. 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 by ATC, cues the pilot to access the RTE page using the RTE mode key. A field labeled "OFFSET" with dashed lines indicating acceptance of entry.

The next cognitive step is to format the entry. The MCDU page offers no help in formatting the entry. It turns out that the format is <side L or R><distance in nm.>. This format must be trained and then recalled in the "heat of battle."

.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

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

Figure 3-a

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.

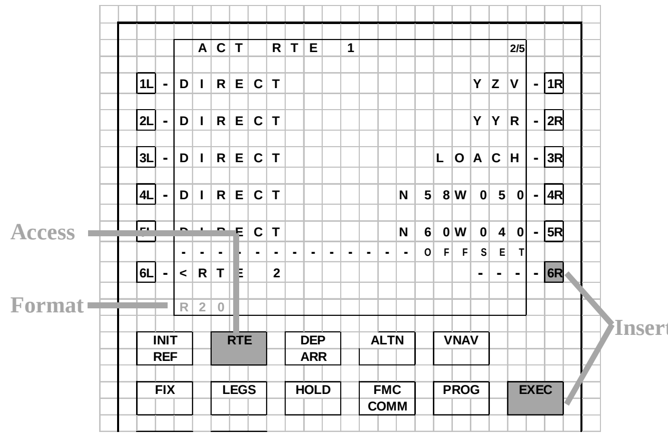
The final cognitive step in this example, once the entry has been typed into the scratchpad, is to select the LS key adjacent the field labeled "OFFSET." This represents an effective user-interface design.

WHEN THE MCDU WORKS WELL (AND WHEN IT DOES NOT)

The RAFI model of pilot-automation interaction identifies several characteristics of the MCDU that create robust pilot-automation interaction . These are described 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 1). The pilot may select a button (e.g. DESCEND NOW on the



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

Figure 3-b

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 1). 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. This 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. 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

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

Sample of tasks supported and not supported by the MCDU/FMS

Table 1

the icon.. Remembering how to find the correct menu item or identify the icon can be very difficult for novel or infrequently performed tasks.

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 (Table 2). One class of Mode keys are associated with mission tasks (e.g. Hold or Direct To). The other class of Mode keys are 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 cued by these labels and 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 ATC clearances and flightplanning with aeronautical charts, constitute a large portion of glass cockpit transition training.

Type	Airbus A320	Boeing 777
Tasks	DIR INIT RAD NAV	INIT REF DEP/ARR FIX HOLD FMC COMM NAV RAD
Symbolic Representations and information	F-PLN SEC F-PLN AIRPORT PROG PERF FUEL PRED DATA	RTE LEGS VNAV PROG

MCDU Mode Keys access MCDU pages to perform tasks or to manipulate symbolic representations or get information. Tasks that manipulate symbolic representations that do not represent the environment require training and memorization.

Table 2

Format (Step 3) and Insert (Step 4)

Once the page as 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.

CONCLUSIONS

The much maligned MCDU exhibits several user-interface characteristics that ensure robust pilot-automation interaction. MCDU features that directly support mission tasks aid the pilot. Labels, prompts, and other visual cues that identify features supported by the automation, access pages, and provide information for formatting and inserting entries, minimize training required and memorized actions. These characteristics reduce training costs and footprints, and eliminate opportunities for pilot errors.

In contrast, the MCDU user-interface provides a brittle user-interface when pilots must reformulate mission tasks to command the automation. Also, in certain cases, the absence of labels, prompts and other visual cues inhibits access of pages, formatting and insertion of entries. These weaknesses can be addressed on the existing MCDU/FMS by:

(1) Establishing the mission tasks and tasks/sub-tasks that are supported by automation (and those that are not).

(2) Adding sufficient labels, prompts, and meaningful feedback messages to enable the pilot to perform the task using the RAFI cognitive steps.

New Graphical User-interfaces for the Flightdeck

Graphical user-interfaces on the flighdeck do not inherently address the issues of Reformulation, Access, Format, and Insertion, although several of the features generally associated with graphical user-interfaces invoke the recognize (not recall) paradigm.

Graphical user-interfaces encourage visual representations of the environment (e.g. graphical flightplans). They provide the means for a "canvas" on which objects can be manipulated, and a "pallette" of manipulations that can be performed. This can provide a user-interface in which representations of the environment are represented in the automation (e.g. aero charts on the Navigation Display). This in turn minimizes the reformulation required from mission task to actions to command the automation.

The other major characteristic of graphical user-interfaces is the application of pull-down menus, dialog boxes, and wizards. These mechanisms significantly simplify and eliminate errors in the access, format, and insert actions.

It should be noted 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 address Access, Format and Insert issues.

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