Merging Control and Feedback to Reduce Mode Confusion in the Cockpit

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Abstract

Mode confusion and automation surprises in aviation raise questions about the design of flight deck interfaces. Prior research investigated the use of the current interfaces and how they can impact the pilot's awareness of modes, and proposed design solutions to reduce mode confusions by improving feedback and interaction with modes. This paper explores a novel design that brings together mode control and feedback in a single interface. The interface aims to reduce mode confusions. Moreover, the paper highlights 5 key dimensions that influenced the design. In the future, we intend to evaluate the proposed interface to validate its benefits.

Keywords

Mode confusion, Mode Control, Flight Mode Annunciation, Automation, Flight Deck Design, Aviation

1. Introduction

While the basic philosophy of the autoflight system in aircraft has become more and more complex in the past years, the way the modes are displayed to pilots has not evolved much. This can make it more difficult for pilots to interpret current flight modes and to be aware of the behavior of the aircraft.

The Flight Mode Annunciator (FMA) is the main display presenting the modes used by the aircraft. Thus it informs the pilot of the current behavior and state of the autoflight system. The current design of the FMA is a basic layout located at the top of the Primary Flight Display (PFD). It indicates "active" modes (currently used by the system) and "armed" modes (waiting to be active when the requirements are met) through a table divided into three columns for autothrottle and autopilot modes. Mode changes are indicated by a white box outline around the relevant mode for ten seconds.

However, the poor and simple design of the FMA does not allow the pilot to be fully aware of the system status. First, the information on the FMA is not sufficient to fully understand the state of the autoflight system [1, 2]. Pilots use other interfaces of the flight deck to find information they need to increase their situation awareness, and those interfaces provide, in most cases, reliable information at a lower cognitive cost than the FMA [3]. Palmer [1] concluded that it is difficult to use information of the FMA because of the physical separation between the Mode Control Panel (MCP) used to engage modes and the FMA, which force the pilot to command a mode in one interface and to verify the effective engagement of the desired mode in another one. Moreover, the FMA is designed for foveal vision while it is in the pilot's peripheral vision most of the time [4]. Consequently, pilots fail to perceive mode changes on the FMA, which results in a lack of awareness [5, 6].

When pilots are not aware of the current states of the autoflight system, they may be in a situation of automation surprise or mode confusion [1, 7, 8, 9] where the system behavior is inconsistent with the pilots' expectations. Automation surprises happen in most interactions between automated system and human beings (driving [10], human-robot interaction [11], use of computers [12]) but these situations become dangerous when it comes to safety-critical systems. Many accidents and incidents in aviation are caused by a divergence of the aircrew's interpretation of the system state from the actual system state [1, 13, 14, 15, 16].

In this paper, we propose a new interface based on 5 key points of design that aim to increase the awareness of the autoflight mode by merging the action and the verification of modes in one single interface. The basic philosophy of the FMA is maintained, but the key points of design make us hypothesize that it will probably increase the awareness and thus reduce the mode confusion.

2. Related Work

Over the years, accidents have allowed us to question the design of the flight deck and to identify interface

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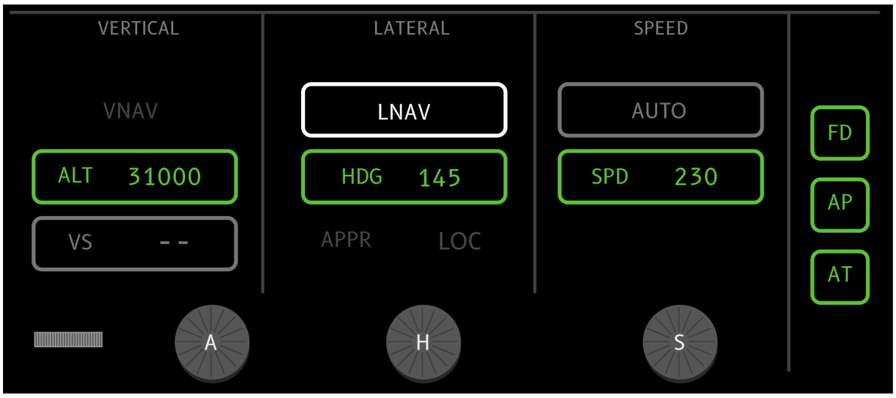

Figure 1: Interactive Flight Mode Annunciator

problems. As flight deck interface issues have been identified, a number of researchers have proposed changes to various interfaces to reduce the mode confusion of pilots. Those new designs aim at providing better feedback for pilots both for input and output.

A first possibility to address this, is to change the way modes are engaged in order to improve the feedback on the control interface. Boorman et al. [17] developed an interface design of the MCP in order to reduce confusion. This new interface focuses on targets rather than modes and gives a clear indication of targets and sources. It was evaluated by 17 pilots [18, 19]. Participants were asked to perform tasks and answered questions about autoflight behavior. Results indicated that the ability to assess the new interface to understand the system's objectives is better than the current interface, although some issues emerged. Rouwhorst et al. [20] presented a touch screen control panel to select targets and engage advanced modes through novel interactions. Hutchins [21] proposed the Integrated Mode Management Interface (IMMI), an interface consisting of a vertical mode manager and a lateral mode manager, which replace the mode controller and provide feedback about the modes of the system and its behavior. Li et al. [22] explored automation feedback design and proposed to move the FMA to the MCP's position. Results showed that moving the FMA next to the MCP could increase pilots' situation awareness.

Another possibility to reduce mode confusion is to augment the feedback by changing the way modes are displayed and by providing better indications about the behavior of the aircraft. The use of icons to indicate autoflight modes and their behaviors has been studied in the literature [21, 23]. Other studies have focused on designing a new FMA format. For example, Feary et al. [24] proposed new FMA labels that indicate the purpose of the system rather than what the aircraft controls. Horn et al. [25] examined a new design which merges the FMA with raw flight data on the PFD and embedded it in the natural scanning pattern of a pilot. Nikolic and Sarter [4] compared the current foveal feedback of the FMA and two different implementations of peripheral visual feedback when uncommanded changes occur. The two peripheral visual feedback types signaled a transition in a more luminous way than the current FMA feedback to capture attention more effectively. Instead of indicating modes, Mumaw [26] proposed to focus on the behavior of the system with a "feedback-oriented" screen. This interface aims to make it possible to interpret the states of the autoflight system in a simpler and more intuitive representation than that commonly used, by showing what autoflight is doing now and what it will do next.

In summary, several researchers have studied novel interfaces to reduce mode confusion. Focusing on the presentation of feedback and engagement of modes seems a promising venue to address issues of situational awareness and mode confusion.

3. Method

In the current paper, we focus on the concern raised by Palmer [1] about the physical separation between the MCP used to engage modes and the FMA by merging the MCP and the FMA, i.e. making the FMA interactive, and hence to provide feedback directly at the location of the pilot's action. To remedy the lack of awareness, we applied a user-centered design process. First, we conducted a series of activities such as interviews with pilots, observation sessions, and focus groups with experts to better understand pilots' behavior in real flight contexts.

Then, we conducted a brainstorming session about new ways of interaction to control modes and new forms of feedback for autoflight modes. We focused on two ideas that were evaluated by pilots through an online survey. The result allowed us to focus our approach on merging the MCP with the FMA i.e. merging the action and the verification in the same interface.

4. Interface Design

We propose a new design that brings together two currently separate interfaces in the cockpit, the MCP and the FMA: the Interactive Flight Mode Annunciator (IFMA). IFMA is a touch-screen interface allowing the pilots to manage autoflight modes and providing feedback about the modes used by the system (Fig. 1). It allows pilots to understand what the aircraft is doing, what the active modes are, who has control of the targets and which automation is engaged.

4.1. Graphical elements - How to verify modes

The philosophy of the FMA is kept in the IFMA which is divided into four parts. From left to right (Fig. 1) : vertical guidance, lateral guidance, speed guidance and the status of the automation. As for the three columns of guidance, the first row corresponds to the modes where the target is managed by the system (following the flight plan) and the second row corresponds to the modes where the target is selected by the pilot (maintaining or tracking heading, altitude, speed). The third differs across all columns.

All modes are visible on the interface and represented by a label associated with a box. Names of modes differ depending on the manufacturer, so we decided to standardize them in our interface:

Vertical guidance There are 3 main modes: VNAV for the automatic vertical navigation ; ALT to maintain an altitude target ; VS to climb or descent with a specific vertical speed. Two additional modes (OP CLB and OP DES) have a different design because they represent a specific behavior in transit to climb or descent by maintaining a speed and those are modes implicitly triggered by the engagement of the ALT mode. They both are represented by a solid green box on the left of the ALT mode (Fig. 2).

Lateral guidance There are 4 modes: LNAV for the automatic lateral navigation ; HDG to maintain a heading target ; LOC to follow the localizer and APPR to engage LOC and GS, the mode to follow the glide slope.

Speed/Thrust guidance We decided to highly simplify the autothrust modes in only 2 modes : AUTO and SPD. The AUTO mode corresponds to a state where the aircraft manages automatically the thrust. In the SPD mode, the aircraft is maintaining a speed target.

Figure 2: Representation of the OP CLB mode. When the aircraft has reached the altitude target, the OP CLB box disappears and the ALT mode is active, thus in green

A specific colour highlights the status of each mode (Fig. 1) :

- Active: green box and label.
- Armed: white box and label.
- Inactive and engageable: light gray box and label.
- Inactive but not engageable: dark grey box and label.

For example, Figure 1 indicates the modes ALT, HDG and SPD are active, which means they are the modes used by the autoflight system. LNAV is armed, which means that the mode will become active once the necessary conditions for its activation are met, and thus the mode HDG will become inactive. VS and AUTO are inactive and engageable : they will be active or armed if the pilot decides to engage them. VNAV, APPR and LOC are inactive but not engageable because some conditions are not fulfilled (VNAV can only be engaged when LNAV is active, and LOC and APPR will only be engageable when the aircraft is close to the airport, thus avoiding the capture of wrong signals).

All modes with which the pilot can interact are represented on the interface. This overview of modes with color coding allows pilots to be aware of engaged modes and those which are not, as well as which modes they can engage and those they cannot engage.

4.2. Interactions - How to control modes

At the bottom of the panel, there are a thumb wheel and three knobs. These buttons allow the pilot to modify the value of the vertical speed, altitude, heading and speed targets (from left to right in Figure 1). The thumb wheel, which allows managing the vertical speed target, is different from the other three knobs because they are not used in the same way. A knob can be turned and pushed when the thumb wheel can only be turned. We chose this design since pilots do not need to hold a current vertical speed because they choose the target before engaging the mode, contrary to the heading, the altitude and the speed they may need to hold at a current value.

There are four types of interactions to control the autoflight system :

- Turn a knob: select the target of the parameter corresponding to the knob.
- Press a knob: maintain the current value of the parameter corresponding to the knob.
- Turn the thumb wheel: select the target of the vertical speed.
- Press a mode (or the status of automation): engage the mode or the status.

The engagement of the HDG, ALT (associated with OP CLB and OP DES) and VS modes by pressing the box must be preceded by the selection of a target. If the pilot presses one of these modes without a preselected target, a brief orange flash appears on the screen to indicate to the pilot that the action has not led to a result. This solution, inspired by ”Red Alert” [27], allows the pilots to understand that there is a problem. This flash also appears when the pilot tries to engage a non-engageabled mode.

Furthermore, if the pilot preselects a target, but the associated mode is not engaged within 10 seconds, then the preselection will be cleared. This time has been chosen arbitrarily and user studies should be conducted to identify the ideal timing. We are aware that pilots sometimes preselect targets and a more or less long time is spent between the preselection of the target and the engagement of the associated mode, but we have chosen to make the ”unused” targets disappear to simplify as much as possible the reading of the IFMA by the pilots.

To disengage a mode, the pilot will have to engage another mode associated with the guidance (i.e. in the same column). For example, if the pilots wish to disengage the LNAV mode, then they will have to engage for example the HDG mode. VNAV mode automatically disengages when LNAV mode is disengaged (the system then engages the ALT mode with the current altitude of the aircraft as target). To disengage an automatism, it is sufficient to press again the box associated with the automatism.

4.3. Key points of the design

We would like to highlight several points that we believe are beneficial in the IFMA compared to existing systems (although this will need to be evaluated in a user study with pilots). These points are listed below and some of them are inspired by the cognitive dimensions of Blackwell and Green [28].

Visibility All modes are permanently visible on the interface.

Consistency The representation of the objects is consistent. Two objects having the same representation are associated with the same interactions (for example, the thumb wheel and the knob have two different representations because they do not have the same interaction).

Selective The pilot can be aware of engaged modes at a glance by the color and position of modes, two selective variables as proposed by Bertin [29]. The pilot also knows which modes are not engageable thanks to the color.

Uniformity The modes’ names are standardized between the manufacturers. This interface can be used in any aircraft.

Proximity This is the main point of the novel design. The action and the feedback are in the same interface.

5. Perspectives

This work in progress needs more improvements. First, the autothrust modes have been simplified (only two in the IFMA) and do not reflect modes related to thrust. This aspect needs more thought. Moreover, there is no possibility in the IFMA to switch between Heading and Track modes or between Vertical Speed and Flight Path Angle modes. We need to investigate how to add these two features while keeping the consistency of the interface. This question is related to the scalability, which needd to be considered: is it possible to add new modeswhileby keeping the current characteristics of the IFMA? Finally, we are aware of the problems related to using touch screens in a cockpit [30, 31]. Yet, touch screens facilitate the evaluation and prototyping of ideas. We will consider augmenting this interface with physical buttons, knobs and thumb wheel to avoid the constraints of touch-related issues in turbulent environments.

This paper proposes a novel design of a mode controller with the goal to have better feedback of the modes used by an autoflight system. The main objective of this design is to merge the mode control and the mode annunciation in one single interface. A future evaluation will determine if this type of interface does effectively reduce mode confusion.

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