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A Vertical Situation Display for Automated Aircraft - Design and Evaluation in Full Mission Simulation

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1 Introduction

This paper presents the design and evaluation of a flight deck display for "glass-cockpit" aircraft that provides feedback for managing the vertical flight path. Capacity and economic constraints may require aircraft to use high levels of automation to follow predetermined 3D/4D flight paths precisely from takeoff to touchdown in the near future. Current aircraft displays provide excellent feedback for managing the automation in the lateral domain, but are lacking similar feedback for the vertical domain. Therefore, during climbs and descents automation surprises occur and may result in incidents or accidents. Additionally, flight crews may not be able to follow given vertical and speed profiles as efficiently and precisely as necessary to cope with the requirements of the increasing air traffic anticipated in the coming years.

2 Design of the Vertical Situation Display (VSD)

Analyzing current and future tasks related to vertical path management and evaluating available feedback resources drove the development of the Vertical Situation Display VSD. The example of the very successful Navigation Display and results from previous vertical navigation display studies contributed to the design as well as inputs from the potential users of the display. A more thorough description of the theoretical background can be found in Prevot (1998).

The VSD is integrated into the cockpit infrastructure to complement existing displays. The constraints on modern flight decks including available display

size, color coding and data accessibility have been taken into account as far as possible and feasible. From this standpoint the VSD could be part of next generation flight decks as well as retrofitted into current generation "glass" aircraft.

The VSD shares the display space with the Navigation Display and can be accessed from the Navigation Display Control Panel in two different views. The first view is a co-planar view of the bird's eye MAP depiction and the along track picture of the VSD. The VSD occupies the bottom 40% of the Navigation Display, which is re-scaled to fit into the top 60% of the display area. In the second view the VSD occupies 80% of the Navigation Display Space and leaves the readouts for winds and waypoints as well as the Heading/Track indication unchanged. Figure 1 shows the co-planar view of MAP and VSD.

Figure 1: Vertical Situation Display in "shared mode"

3 Full mission simulation study

In fall 1998 a full mission simulation was conducted at NASA Ames' Advanced Concepts Flight Simulator (ACFS) to investigate flight crew factors for Flight Management System (FMS) usage in the extended terminal airspace. The ACFS is a full-mission simulator with a "generic" glass cockpit layout based on current generation Boeing-type displays. The simulation model represents a Boeing 757. Twelve airline flight crews participated in the study and flew seven descents from cruise altitude to touchdown in the Dallas Fort Worth airspace. The crews were subject to different interface conditions. They were required to fly at different levels of automation, ranging from current day procedures, requiring step-by-step entry of target values for altitude, speed and heading into the autopilot to fully automated modes, coupled to the FMS until final approach.

The main purpose of the study was to investigate crew interfaces that enhance the compatibility between ground automation and flight deck automation.

The VSD was an independent variable in this study made available to half of the crews. Crews provided with the VSD were free to select the co-planar or the full mode at any time. They were asked to turn it off in the final phase of flight, because the VSD was not designed for controlling aircraft during approach.

A comprehensive data analysis is still ongoing, evaluating aspects of crew performance, workload, acceptance and subjective assessment of several interface modifications. The following paragraphs present an overview on some general results and discuss the particular results on the subjective assessment of the VSD by the flight crews and how they were using it. For details on other aspects see Crane et al. (1999).

4 General results

The flight crews considered the scenarios flown realistic for moderate traffic situations, but not very challenging. Overall flight crew performance was at a very high level for all interface conditions and runs. The VSD did not affect this overall high crew performance. The workload assessment using the NASA TLX methodology showed no significant differences between the crews having the VSD available and those, who did not.

We believe that in order to expect differences in workload or crew performance caused by the VSD more challenging scenarios are required including higher traffic density and worse weather environments.

5 Subjective assessment by the flight crews

The six flight crews that had the VSD available were asked to state their opinion and experience with the VSD in a questionnaire at the end of the experiment. 11 Results from 6 first officers and 5 captains were received. Table 1 summarizes the main questions. The subjects were also asked which display features they found most helpful. The following features were named most frequently:

1. Magenta vertical flight path depiction:	9
2. Altitude/speed crossing restrictions:	8
3. 1 minute green flight path angle predictor line:	7
4. Altitude display, speed display, speed bug value, color coding for managed and unmanaged crossing restrictions:	4-5

Comments on the flight path depiction stated that it's "easy to interpret", a "planview of descent" and "same as magenta LNAV path, it's where we want to

be". The crossing restrictions were said to be a "good memory aid", "allowed advanced planning to stay ahead", "Not too useful", "Very useful", "easy to read" and "too small".

Question	Answer-option				
Did you feel more "ahead" or less "ahead" of the airplane with the VSD?	*Much less* 0	*Somewhat less* **1**	*Border line* 0	*Somewhat more* **5**	*Much more* **5**
Did use of the VSD distract you from performing other cockpit tasks?	*Yes* 0		*No* **11**		
Did use of the VSD distract you from monitoring other cockpit displays?	*Yes* 0		*No* **11**		
In general, how helpful or unhelpful was the VSD in aiding your management of the descent?	*Very unhelpful* 0	*Somewhat unhelpful* 0	*Border line* 0	*Somewhat helpful* **4**	*Very helpful* **7**
Did having the VSD increase or decrease your monitoring demands?	*Greatly decreased* 0	*Somewhat decreased* **2**	*Unaf-fected* **3**	*Somewhat increased* **6**	*Greatly increased* **1**
Did having the VSD increase or decrease your overall workload?	*Greatly decreased* 1	*Somewhat decreased* **5**	*Unaf-fected* **3**	*Somewhat increased* **2**	*Greatly increased* **0**
Did the VSD help you to understand how the FMS manages the flight path?	*Yes* **7**		*No* **4**		

Table 1: Summary of questionnaire

6 Usage of the Vertical Situation Display

The crews were trained on how to interpret the VSD in a 15 minute briefing using display snapshots, in which the symbology was explained. They were briefed on how to select and deselect the two available modes co-planar and full VSD, and told to deselect the VSD during final approach. Figure 2 shows the time the VSD was used in relation to the flight time from cruise altitude to 5000 feet for 40 runs performed by 6 different flight crews.

Usage of the VSD was very inconsistent throughout the subjects, as the big standard deviations indicate. One captain hardly ever used it, whereas many subjects used the VSD during the entire descent. In average either the Pilot Flying (PF) or the Pilot Not Flying (PNF) had the VSD selected during 75% of the flight time. Both crewmembers used the VSD simultaneously for 30%. The shared co-planar mode was clearly preferred and used almost all the time (>98 %) the VSD was selected. The full mode was rarely used and only for a few seconds. VSD usage between the PF and the PNF was similar.

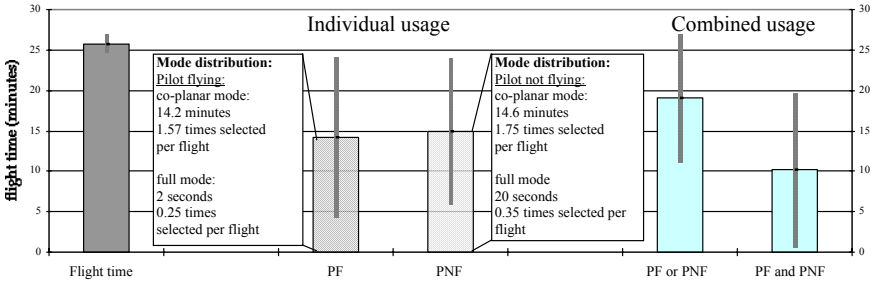

Figure 2: VSD usage in relation to flight time from cruise to 5000 feet. Mean and standard deviation. Sample size: 40 runs with 6 flight crews, each at least 5 runs with alternating positions

7 Discussion

The very positive crew feedback and frequent usage of the VSD demonstrate that design and integration of the VSD are appropriate for current glass cockpits. Subjectively the crews indicate to be more ahead of the airplane, not distracted by the VSD and get a better understanding of the aircraft automation. This possible enhancement in situation awareness did not result in a significant difference in crew performance or workload in this full mission simulation. However, this study did not present very challenging tasks or abnormal situations, whereas situation awareness usually becomes a key factor in cognitively demanding situations.

8 References

Prevot, T. (1998) A Display for Managing the Vertical Flight Path – an Appropriate Task with Inappropriate Feedback - *Proc. HCI Aero '98*, Montreal, Canada, May 1998.

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