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Interactive Head Up Display in the Cockpit to reduce Crew Workload

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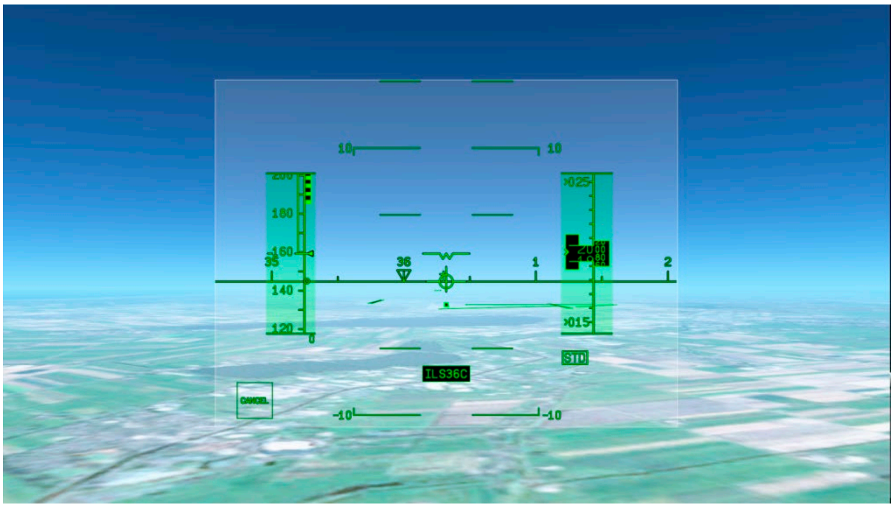

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Problem area

Head-Up Displays (HUDs) are gradually finding their way into the cockpit of commercial aircraft. By presenting primary flight parameters on a HUD, pilots can remain heads-up instead of switching between instrument panels inside and the outside view. Currently executed research is looking beyond the possibility of providing flight guidance to the flight crew with a HUD, by exploring the possibility to also interact with the symbology presented, through eye-gaze in combination with a manual input device. The objective of which is to reduce crew workload.

Description of work

Several applications of interactive HUD symbology were developed. The applications are targeted at the role of the pilot monitoring, who can change parameters to impact aircraft guidance and control. By using an eye tracker installed in a cockpit mock-up and presenting HUD symbology on the outside view, several scenarios were flown to determine the effect of the concept on workload.

Results and conclusions

The results show that the HUD interaction is rather intuitive and easy to do, provided that the eye-tracker is well calibrated. It was concluded that given the advanced cockpit environments of today, it is difficult to reduce workload, by changing the input modality. Changing a parameter setting is not very effortful since the current cockpit interface is highly optimized and pilots are so much used to their current working method. However, providing novel functionality through the HUD that replaces a number of steps by a single selection on the HUD, such as changing the selected runway, has potential to make a difference.

Applicability

The applications can be applied to aircraft operations – both civil and military - with a HUD and parts may also be useful for Head Mounted Displays.

GENERAL NOTE
This report is based on a presentation held at the H-Workload, Amsterdam, September 2018.

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Abbreviations

ACRONYM	DESCRIPTION
ATC	Air Traffic Control
ERP	Eye Reference Point
HUD	Head Up Display
NLR	Netherlands Aerospace Centre
SA	Situational Awareness
SVS	Synthetic Vision System

1 Introduction

1.1 Head Up Displays

Multiple studies have been performed to research the effect of using Head Up Displays (HUDs) on pilots in certain flight phases [1], [2]. Particularly during landing in low visibility, a HUD provides essential cues for accurate alignment with the runway thereby allowing lower landing minima compared to not having such a device. Presenting primary flight parameters on a HUD, allows pilots to stay heads-up instead of switching attention between instrument panels inside the cockpit and the outside view. As such it may increase Situational Awareness (SA) and reduce workload.
HUDs have been in use in the military domain for decades, allowing the crew to stay heads up in air-to-air combat, when verifying primary flight and mission parameters. More recently, the HUD technology found its way into civil aviation. Firstly, primarily business or private jets were equipped with HUDs allowing them to land on smaller airports where little landing facilities are provided. Nowadays, large passenger aircraft such as the Airbus A350 and the Boeing 787 are being delivered with HUDs for use throughout the flight.
In the research we are looking beyond the possibility of providing guidance to the flight crew. We are exploring the possibility to also interact with the symbology presented on the HUD, through eye-gaze in combination with a manual input device. Literature reveals no application of this technology in aviation. In the automotive industry however some initiatives are ongoing to control non critical functions on the HUD through hand gestures [3]. For as far as we could find, interactive HUD systems through which to perform flight critical tasks do not exist nor is there any publicly available research on this subject.

1.2 Background

Workload is defined in this paper as the amount of cognitive load a human operator experiences. It is subjective: one operator may experience a high workload with a task, where another may experience a low workload. Personal characteristics and experience on a task play a large role. Task load on the other hand, can be considered an objectively quantifiable load, for example the number of sub-tasks to be performed.
Airliners are flown by a two pilot crew. And it is typical for information systems in the cockpit to be redundantly integrated in the cockpit: both pilots have access to the same information. Typically the roles of pilot flying and pilot monitoring are distinguished. The pilot in command of the flight, generally the one with the highest rank, like a captain, designates who will be the pilot flying for a particular flight segment. The pilot flying will be the pilot actually flying the aircraft and managing the flight path, while the pilot monitoring (alternatively named pilot non flying) communicates to the outside world, takes care of the navigation and works off checklists. The pilot monitoring is – as the name is implying – also cross-checking and monitoring the flight path and control activities of the pilot flying.
Certain events during flight can suddenly increase the task load in the cockpit and cause one of the pilots to be head-down. This is typically the case when the flight gets a new runway at a rather late moment in the approach. In this case the pilot flying should fly towards the other runway and the pilot monitoring needs to make several changes in the flight management computer to prepare the aircraft systems related to that new runway. Allowing the pilot monitoring to make a single selection on the HUD that would replace these actions on the flight management computer could make a difference in task load and consequently in workload.

2 Concept

The concept consists of a HUD with 2D symbology of the basic parameters from the Primary Flight Display (primarily speed, altitude, heading and aircraft attitude). Also a 3D layer with a Synthetic Vision System (SVS) presenting an analogy of the real world can be visualised. This is used typically during landing, where it visualises the horizon and the runway outline in a world-conformal way.

To interact with the HUD symbology the pilot looks at the symbology (for example the speed symbol) and presses a knob (a combined button and dial). When rotating the knob a new value can be selected. Pressing the device again acknowledges the newly selected value. This is how Speed and Altitude could be altered in the concept. Naturally the symbology provides feedback to indicate the interactive state and the current selection.

When the runway symbol is visible in the area covered by the HUD, the pilot (flying) can change the currently selected runway by looking at the airport and pressing the knob. The HUD interaction would no longer require the pilot monitoring to look downwards but immediately send the new desired runway to the flight management computer, which will update the navigation display and go-around procedures.

After having pressed the knob, initial selection starts and other runways are visualised in the HUD symbology. Rotating the knob toggles through the available runways at the destination airport. Subsequently pressing the knob will select the new runway. Also in this case the symbology provides feedback regarding the interactive state as well as the current selection.

In addition to the 3D symbology in the HUD, the currently selected runway is also indicated in the lower area in 2D symbology – irrespective whether the runway is in the HUD field-of-view or not. This indication can also be selected with eye gaze interaction in a similar way as altitude and speed selections. In this case a menu-scroll option becomes visible after selection.

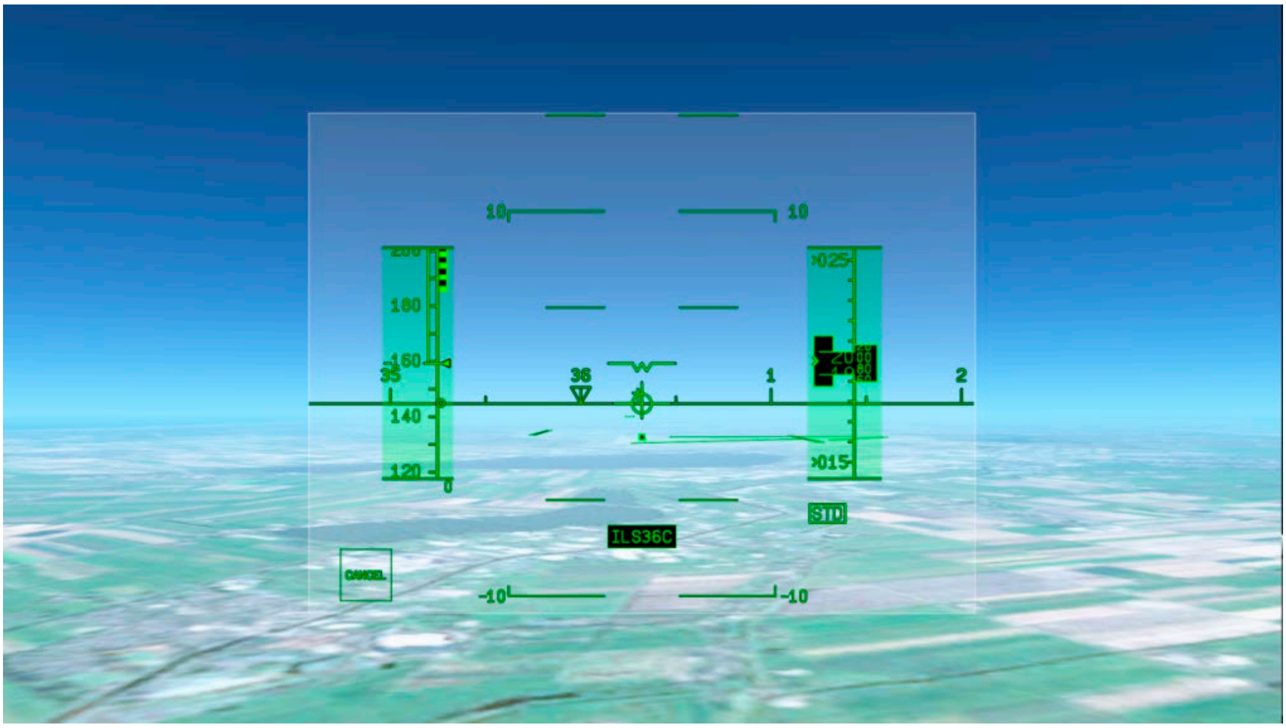

Fig. 1 The HUD in the approach (2D)

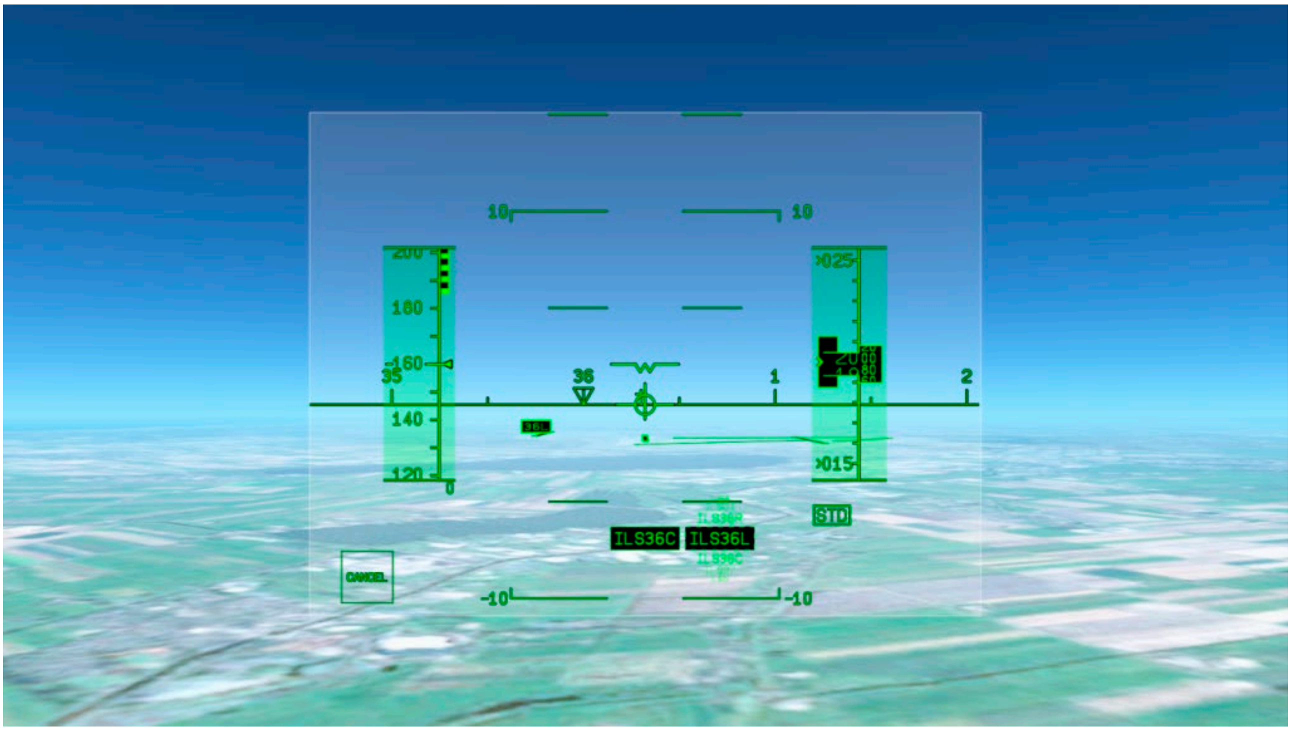

Fig. 2 The HUD, while the participant is selecting a new runway (2D)

In case of the interaction with the 3D layer, the outline of the active runway becomes visible in the area covered by the HUD at around 10 mile before the runway. From that moment onwards, the pilot can change the currently selected runway using eye-gaze interaction.

A cancel method is implemented in case the pilot inadvertently changes a parameter but has not yet pressed the knob to acknowledge. Cancelling is done either by looking outside the sensitive area around the selected parameter and pressing the knob or by looking at a dedicated cancel area on the lower left corner of the HUD and pressing the knob. The cancel area is only visible when a parameter is selected.

3 The experiment

3.1 Objective

The objective of the experiment with the interactive HUD system was threefold:

- To verify the usability of the concept of an interactive HUD system with eye-gaze;
- To compare the usability of two ways of cancelling: look away and cancel area;
- To compare the usability of two ways of interaction: interaction with the 2D symbology and the 3D in case of the runway selection.

3.2 Participants

With the objective to evaluate the usability of the interaction, the experiment participants did not need to be airline pilots. A combination of pilots and students were invited. Four students were invited to participate in the experiment. Most of the students did not have any flying experience, but had some familiarity or at least affinity with flying. Of the seven participants, three were pilots (one airline pilot, one former F16 pilot and one glider instructor). The new concept was evaluated with a single pilot setup.

3.3 Procedure

Four conditions were tested. In condition 1 and 2, speed and altitude changes were instructed by Air Traffic Control (ATC). The participant was to repeat the instruction and change the setting using the interactive HUD concept. In both conditions one of the instructions was withdrawn by ATC, as to have the participant cancel the action to test this functionality. In condition 1 the pilot was to cancel by looking away from the selected parameter in the HUD and meanwhile pressing the input device. In condition 2 a cancel area was visualised on the lower left corner of the HUD. Looking at the area and pressing the input device cancelled the action.
In conditions 3 and 4, a late runway change was instructed by ATC. In conditions 3 the change was made through the 2D menu and in condition 4 through the runways presented in the SVS.
After each run a questionnaire was filled in by the participant on the following topics:

- Workload (Modified Cooper Harper for controllability);
- Information density;
- The ease of performing the different tasks in each scenario/condition.

Table 1: Experiment test conditions

Condition	Action	Cancel
1	Speed and altitude change Cancel	Look away
2	Speed and altitude change Cancel	Dedicated cancel area
3	Late runway change, 2D	Cancel area
4	Late runway change, 3D	Cancel area

3.4 Environment and measurement equipment

The experiment was held in NLR's fixed-based cockpit mock-up APERO (Avionics Prototyping Environment for Research and Operations. It consists of a cockpit console with seats, representing the cockpit physical dimensions. The outside view is presented on a large display located about 1.5 meter from the Eye Reference Point (ERP).

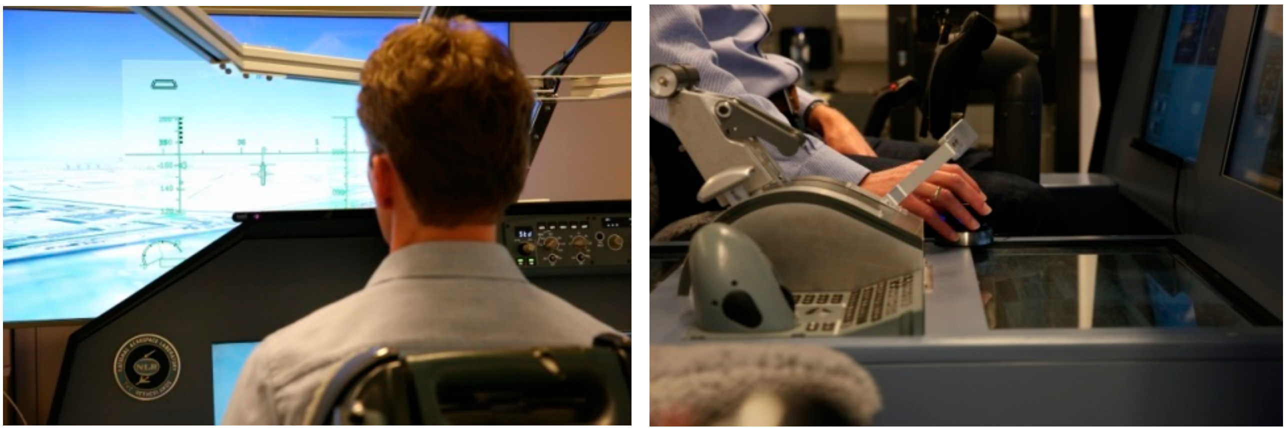

Fig. 3 The experiment set-up in APERO

The eye tracker (Tobii, Fig. 4) and the manual input device (Space Navigator, Fig. 5) were used to operate the interactive HUD system.

Fig. 4 Tobii bar eye-tracker

Fig. 5 Space navigator

The participants were briefed about the concept and got the opportunity to practice using the HUD interaction (for about 10 minutes) before executing the test conditions (Table 1). The runs were performed once by each participant and the order was randomised.

4 Results

4.1 Making speed and altitude changes through the HUD

In condition 1 and 2 questions were filled in regarding the selection of speed and altitude (**Fig. 6**). The average ratings were taken for those instances where the selection was not cancelled.

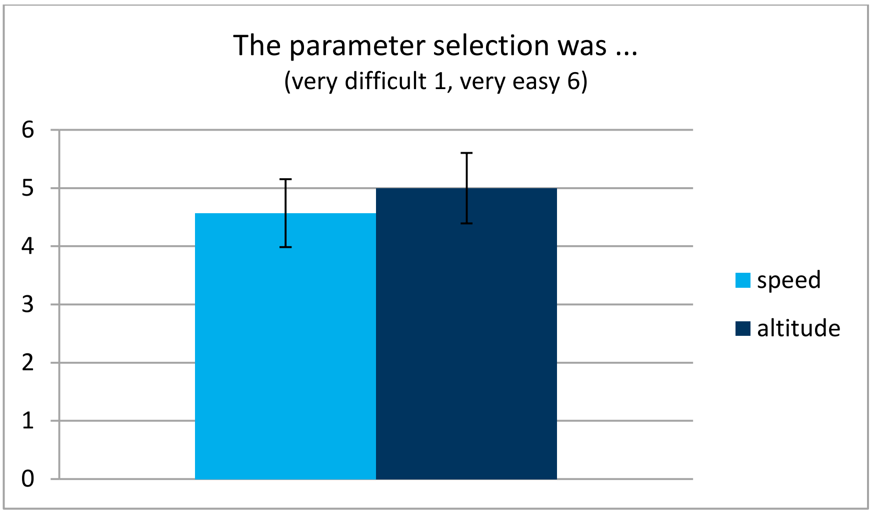

Fig. 6 Average ratings of parameter selection speed and altitude (error bar presents the 95% confidence interval) N=7

4.2 To cancel a selection when it is not yet acknowledged

It was verified which mode of cancelling was more convenient: looking away from the parameter to be selected towards a non-sensitive area in the HUD or looking to a specific cancel area that is presented at the moment a selection is being made.

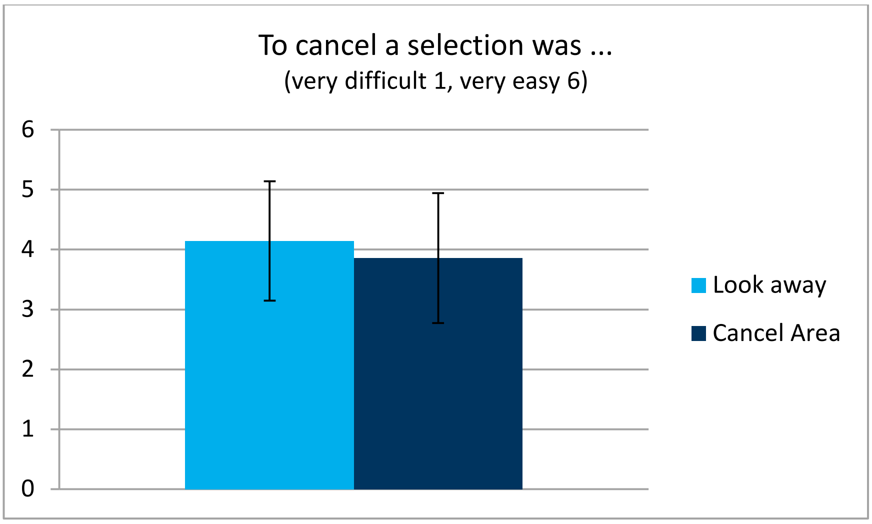

Fig. 7 Average ratings of cancelling a selection by looking away or by looking at the cancel area (error bar presents the 95% confidence interval) N=7

4.3 To make a late runway change

Making a late runway change was evaluated using the 2D menu and the runway visualisations in 3D. The results are presented in Fig. 8.

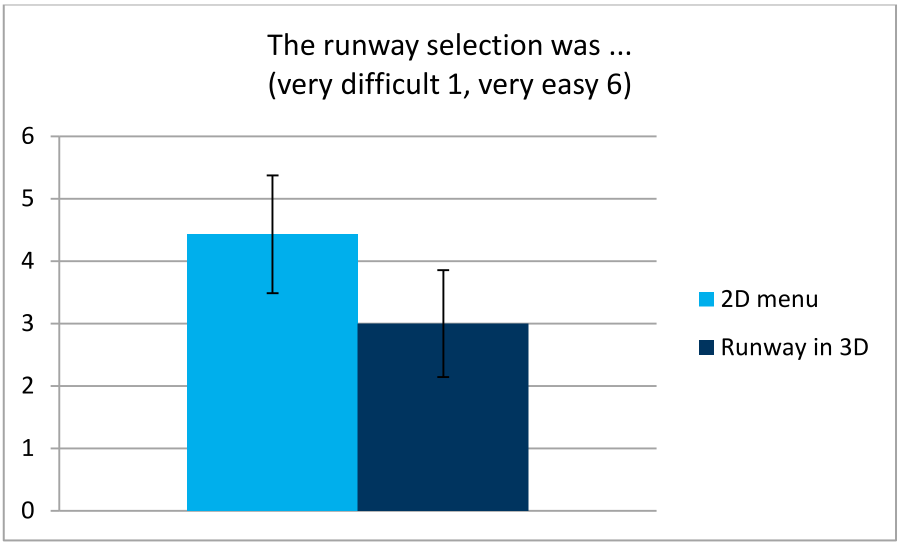

Fig. 8 Average ratings of the ease of selecting a different runway using the 2D menu and 3D (error bar presents the 95% confidence interval) N=7

The difference in the ease of selection between the 2D and 3D symbology is significant with a two-tailed T-test (*p=0.0004*).

5 Conclusion and discussion

The experiment showed that the concept could work. All participants were able to make the selections that were part of the scenarios. Making selections of speed and altitude was rated as rather easy (rated on average higher than 4.5 on a scale of 1 to 6). To cancel a selection was on average rated slightly more effortful (rated around 4 on a scale of 1 to 6).

To cancel by means of looking away or by looking at a specified area did not provide significant differences. Some participants had a preference for looking away and others for the cancel area. By looking at the cancel area there was no possibility to inadvertently cancel the action. One of the participants mentioned to prefer an option where the selection status is automatically cancelled when the pilot is not manipulating the selected parameter for a certain number of seconds.

To change the runway at a late moment in the approach was rated significantly easier using the 2D menu compared to the 3D interaction. In 3D the runway are visible at a rather late stage (around 10 miles from the airfield). At a larger distance the individual runways cover a too small area in the HUD. One of the pilots expressed his doubts about the concept of facilitating a late runway change. He mentioned that it should not be encouraged to change the landing runway in a late stage (10 mile in advance of the runway), and that might be a reason not to enable the pilots to do so as it increases the workload and puts pressure on regaining the mental picture.

No baseline configuration was compared in the experiment. Neither was the crew concept addressed specifically since a first investigation step into the concept evaluation was executed in a single pilot experiment. Therefore no clear-cut conclusions can be drawn on a (crew) workload reduction in comparison to the conventional cockpit yet. It can be expected that changing the speed and altitude through the HUD concept – which is normally done by means of a rotary knob on the glareshield – will not drastically impact (decrease) the individual crew member’s workload, because that is already a highly efficient, routine, and simple action. However, for the runway selection task a serious reduction in workload can be reasonably expected. The easy action through the HUD replaces several actions to be performed heads-down. Moreover, the real advantage of the interactive HUD is in that the pilot monitoring, who generally is executing this task, can remain heads-up, by which he/she can maintain SA. And therefore no cognitive resources are used for regaining SA.

A general observation was that sometimes the eye-tracker needed to be recalibrated during the experiment. Also, with some participants the calibration was much easier than with others. It shows that some eyes are easier tracked than others. It may be concluded that the eye gaze interaction could be implemented in addition to the existing interaction means but not yet replace it.

6 Acknowledgement

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