

# THE APPLICABILITY OF AN ADAPTIVE HUMAN-MACHINE INTERFACE IN THE COCKPIT

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## ABSTRACT

This paper addresses the applicability of an Adaptive Human-Machine Interface (AHMI) in the modern aircraft cockpit. The basic underlying hypothesis of adaptive interfaces is that different display configurations are more appropriate in particular situations. A well-designed adaptive interface that is able to present the right information in the right format at the right time could help the pilot in establishing and maintaining situation awareness. The main functions of an adaptive interface are a goal/context manager and a display manager, including a subfunction for prioritisation of alerts. Different levels of adaptation are illustrated with examples, allocating the different stages of the adaptation process to the human or automation. To be able to help the pilot performing the task, the interface needs to have at least the same knowledge as the pilot.

## KEYWORDS

Flight Deck, Adaptive Interface, Intelligent Interface, Automation, Human Factors.

## INTRODUCTION

Accident analysis shows that accident rates do not decrease and the number of accidents attributed to human error stays at a constant level of some 65% [RAND, 1993]. This in spite of numerous cockpit automation efforts to increase the overall aviation safety.

With the advance of technology, many of the functions on the flight deck of commercial aircraft that were previously performed manually have become automated. Currently, there are two types of automation available in the cockpit. With *control augmentation*, the control of the aircraft is handed over to the autopilot, the functioning of which is monitored by the pilot. By engaging *display augmentation*, the pilot orders the automation to present a set of steering commands that can be directly applied to the aircraft without any cognitive processing [Mulder, 1999]. This traditional automation only provides help on the skill- and rule-based level [Rasmussen, 1983], resulting in a reduced manual workload. However, it places the pilot in the position of being a monitor of automation, a task for which humans are not particularly well suited [Wiener et al., 1980]. It seems that the reduction in manual workload goes to the cost of an increase in mental workload.

In most cases, pilot errors are not simply due to human mistakes, but are rather a logical consequence of a lack of *situation awareness*<sup>1</sup>

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<sup>1</sup> 'Situation awareness (SA) is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future' [Endsley, 1995]. For the SA of the flight crew, the environment includes the aircraft; for the SA of the aircraft systems, the environment includes the human pilot.

(SA). To form an internal representation of the flight situation, the crew has to integrate a large amount of information. Flight, environment, and system state information is presented to them on numerous head-down cockpit displays in different formats. In addition, the auditory channel is used to alert the crew in case of a hazardous situation. With the increase of cockpit complexity and automation, pilots have difficulties to obtain situation awareness, especially during critical situations when this awareness is of greatest importance. In addition, in the future Air Traffic Management system, traffic situations will become even more complex and the pilot will need an even better situation awareness, as the traffic will no longer be channelled along fixed routes and the pilot will be responsible for defining the preferred trajectory [Mulder, 1999].

Replacing the human by automated functions that take over the human's tasks as in traditional automation does not reduce the number of accidents caused by human error. Instead, automation should work alongside the human operator. There is a need for a knowledge-based support system that helps the pilot in establishing and maintaining SA and in making decisions: a knowledge-based Adaptive Human-Machine Interface (AHMI) that integrates all information necessary for SA building.

## WHAT IS AN ADAPTIVE HMI?

Early user interfaces have been static. The system designer built the interface and the user had to learn how to use it. Today, a more flexible interface is the state of the art. The opportunity to accommodate the interfaces to their own preferences is given to the users. This is called an *Adaptable* or *Flexible Interface*. On the current flight deck, several flexible displays have different presentation modes that can be selected by the pilot. An *Adaptive Interface* goes one step further. It assists the users in the adaptation of the interface to their own needs and preferences or performs the adaptation automatically [Dieterich et al., 1993]. Adaptation to the user and/or situation, is one of the functionalities of an *Intelligent Interface* [Tyler, 1991], also known as a *Cockpit Assistant* [Onken et al., 1994 and Onken, 1997] or *Pilot's Associate* [Hammer, 1996]. Other functionalities are inference and evaluation of user plans and intentions, error detection and correction, and the execution of some actions on behalf of the human [Tyler, 1991]. Outputs of the AHMI are warnings and hints, current and future flight status, answers for

crew requests, and proposals for flight state changes [Gerlach, 1993]. These outputs are based on information coming from several different sources, which are discussed further in this paper.

Only the adaptation functionality of the intelligent interface is considered here. Based on the results of flight tests [Onken, 1997], it is expected that an AHMI that intelligently presents the right information at the right time in the right format could significantly reduce the number of human errors in flight.

This paper only considers adaptation of the presentation of information to the user. The adapted constituents are the display configuration, the amount of information presented on the display, the level of detail, the modality, and timing strategy.

Note that in contrast to adaptation in some other domains, such as television or mobile telephones, the adaptive cockpit interface does not adapt to the user. All pilots have had the same training and are considered as one and the same user.

## THE PURPOSE OF THE AHMI

As mentioned before, the purpose of an AHMI is not to automate more of the tasks performed on the aircraft, but to provide some intelligent assistance to the flight crew in the acquisition of their SA. Onken [1994] defines a basic requirement for interface design to overcome overcharges concerning situation awareness:

*'On the basis of comprehensive machine knowledge of the flight situation resulting in smart presentations of situation-relevant messages, it must be ensured that the attention of the cockpit crew is directed towards the situation-specific, most urgent task or sub-task.'*

Thus, the channels for information presentation should be managed to present the right information in the right format at the right time.

### *Present the right information ...*

Traditional interfaces deluge the pilot with data, much of it irrelevant at that particular time, forcing the pilot to integrate the data into useful information. By presenting only the information necessary to perform a certain task specific to the current situation, the crew no longer needs to filter out the important information. For example,

when a TCAS<sup>2</sup> advisory occurs, only the relative position of the threatening traffic is important. The presentation of the other surrounding traffic is then more annoying than useful.

As can be seen from its definition, for SA building, the presentation of numerous pieces of data (even if few in number) is not sufficient. The information must be placed in a present and future context. For example, it is of no use to know that the aircraft is flying in East-direction if the relative position of the destination is not known.

Also warnings and hints should be placed in the appropriate context. In a certain flight situation, certain warnings may be irrelevant. If an aircraft is deviating from a standard procedure, the warning systems will generate alerts. For example, an aircraft could deviate from the standard arrival procedure for a certain airport. This deviation could however be on purpose. In that case, the alert may be irrelevant and should not be given. How does the automation know whether the deviation is on purpose or not? This is the task of one of the other functionalities of the intelligent interfaces: inference and evaluation of user plans and intentions in the context of the current and predicted flight status.

*... in the right format ...*

To quickly achieve a good SA, the information should be perceived intuitively. The information has to be presented in a way that is most easily perceived by the human pilot. The best display configuration may depend on the situation. For example, during the approach phase of flight, SA may be achieved more easily if the aircraft position relative to its environment is presented in a three-dimensional manner, such as with tunnel-in-the-sky [Mulder, 1999]. During level cruise flight however, it may be more efficient to use the traditional Navigation Display (ND) and Primary Flight Display (PFD), presenting a top-view of the traffic situation and the pitch and roll attitude respectively.

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<sup>2</sup> The Traffic alert and Collision Avoidance System (TCAS) issues advisories against predicted aircraft collisions. It is a last resort tool to prevent near mid-air collisions. Advisories are given 15 to 50 seconds before a predicted collision [FAA, 1990].

Another situation-dependent characteristic of the information presentation is the level of detail. For example, during an aircraft conflict alert, the presentation could zoom-in on the encounter, adding identity, velocity, intent and other information of the involved aircraft.

Further, different presentation modalities should be used. In the aircraft cockpit, most information is perceived visually. Sometimes, the auditory channel is used. For example, aircraft position and attitude information is presented visually, while aircraft system status can be presented audibly. For time-critical warnings both the visual and auditive channel are used.

Information about different aspects of the situation (for example traffic, terrain, and weather) should be presented in an integrated manner. This requires some integration on a lower level. Mulder et al. [2000] suggest an agent architecture for the integration of aircraft warning systems.

*... at the right time.*

As mentioned above, information about different objects coming from different sources should be presented in an integrated manner. Most of the time, the information can be combined to form one picture or message. However, in time-critical situations, such as when a TCAS advisory is issued for example, some information is more important than other. Timing is then of great importance. To present the information in a suitable order, a priority assessment must be made. Each message is evaluated mainly on the importance of the message in the actual flight phase and its thematic relationship to the last issued message [Gerlach, 1993].

## **WHAT ARE THE RISKS OF ADAPTATION?**

The success of the AHMI depends highly on the acceptance and trust of the user. If a tool is not accepted by the pilot, it will not be used, or at least not to its full extent. One of the most important factors for acceptance by the pilots is that the pilot should always be in control. The pilot should at all times have the opportunity to overrule the adaptation. Another important factor is that the user should always be able to understand the adaptation. The adaptation is done to improve the SA building and should not raise extra questions. Further, the adaptation may not disturb the pilots in their performance.

## ADAPTATION KNOWLEDGE

As mentioned before, the purpose of an AHMI is to help the pilot in establishing and maintaining situation awareness. To be able to do that, the interface needs at least the same knowledge as the pilot has.

The interface first of all needs a full awareness of the situation: the flight state (flight plan, position, velocity, etc.), environment (weather, traffic, airports, etc.), and system state (system failures, etc.). As will be seen in the next section, this information is compared with the goals of the human-machine system. During flight, these goals can be dynamic, such as the final destination, or the next waypoint, or static, such as safety, efficiency, and company preferences. The goals are placed in an order of importance. For example, at all times, safety is a higher order goal than following the flightplan. The output of the comparison are goals that can not be achieved due to the situation (for example, the goal of following the flight plan can not be achieved because there is an aircraft collision predicted) and goals that require an action of the pilot (in the same example, to ensure safety, the collision must be avoided by an avoidance manoeuvre).

A combination of a certain environmental situation and a set of goals determines a pre-defined procedure. A procedure defines the actions a pilot has to perform to achieve the goal in that particular situation. These standardised procedures are taught to the human pilot during training. To help the pilot performing the task in a correct and efficient manner, the interface needs to be familiar with these procedures too.

Finally, for every procedure, the interface has to know the preferred display format.

## THE FUNCTIONALITIES OF AN AHMI

Summarising the purpose of the AHMI, the interface should first decide what information is needed for building a SA that is appropriate for the current situation and future plans. Next, a prioritisation has to be made. Finally, the information has to be integrated in the right format, i.e. the appropriate display configuration, level of detail and modality have to be determined.

The core of the intelligent interface is the

*Selector* [van Paassen et al., 2000]. It combines the current goals with the actual and predicted situation to determine the most appropriate procedure and a recommendation for the *Interface Mapper* that controls the information presentation. The Selector has the following functionalities:

- *Goals/Constraints Mapper*: This mapper combines information about the goals of the operation with the knowledge of the situation to determine the relevant information that should be presented to the pilot.
- *Prioritisation of alerts*: This function is responsible for avoiding an overload of messages in the cockpit. It gives the alerts an order of importance (see also [Mulder et al., 2000]).
- *Display Manager*: This function determines the appropriate format for the relevant information: the modality, display configuration, and level of detail.

## THE LEVEL OF ADAPTATION

According to Dieterich et. al [1993], four stages can be distinguished in the adaptation process: initiation, proposal, decision, and execution. The agents performing or controlling these stages are the pilot or the automation. Consequently, sixteen combinations (two agents with four stages) have to be considered. However, some of the combinations are unreasonable:

- It is not reasonable to make the user execute an adaptation that was decided by the automation, regardless of the agent performing the initiative and proposal.
- Asking the user to execute an adaptation proposed by the automation is also a less reasonable variant.
- It is not reasonable to ask the user to propose alternatives for adaptation while the automation performs all other tasks.

Eliminating these unreasonable combinations leaves six combinations<sup>3</sup>. Examples illustrate the

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<sup>3</sup> In fact, it leaves eight combinations. For the two last combinations however, the adaptation can either be executed by the user or automation.

applicability of these adaptations on the flight deck:

- *Self-adaptation*: the automation performs the tasks on all stages of the adaptation. This adaptation is contradicting with the human-centred design philosophy and seems therefore unacceptable. However, in certain time-critical situations, it may be necessary to automatically adapt the interface to draw the crew's attention and to allow an immediate but sound response. 'Self-adaptation is particularly suitable for adapting to the requirements of the application' [Dieterich et al., 1993]. For example, if the ND would automatically zoom-in on the encounter when a TCAS advisory occurs, for example to a range scale of 10 Nautical Miles (NM), the attention of the crew is then immediately drawn to the threat and a lot of time can be gained. Because the adaptation is unexpected and may cause confusion, its occurrence must be well known and trained by the cockpit crew.
- *User-controlled self-adaptation*: the decision to adapt is taken by the user, while all other tasks are automated. If the automation thinks that for the current situation a different presentation may be more efficient, it may suggest an adaptation that has to be agreed upon by the pilot. For example, during cruise flight under normal traffic and weather conditions, a range scale on the ND of 100 NM is more appropriate than a scale of 10 NM. If the range scale is still 10 NM after for example resolving a TCAS alert, the automation could then suggest to change the scale. A simple 'Yes' of the pilot is then sufficient to execute the adaptation. A 'No' or no answer at all would result in the suggestion being disregarded.
- *User-initiated self-adaptation*: the user takes the initiative, the automation proposes, decides and executes. This is in fact self-adaptation, but allowing the user to take the initiative. As mentioned before, during the approach phase of flight, the tunnel-in-the-sky presentation may be more efficient than the traditional PFD. When the initiative to start the approach is explicitly taken by the pilot, the automation can propose, decide and execute a change of display configuration.
- *Computer-aided adaptation*: on a user's initiative, the automation proposes an adaptation, which it will execute after the user's approval. For example, in a high traffic density area, the ND presenting the relative positions of the surrounding traffic may be very crowded. The user may then request the automation to declutter the display. The automation could then for example suggest to remove all traffic that is more than 2000 feet above or below the own aircraft. If the pilot agrees, the traffic is removed. If the pilot disagrees, the automation proposes another adaptation to declutter the display.
- *System-initiated adaptation*: on a system's initiative, the user proposes, decides and executes the adaptation. 'The user is informed if it seems reasonable to tailor the system' [Dieterich et al., 1993]. For example, suppose the ND range is set on 50 NM and an aircraft is approaching at a distance of 70 NM. Since the target is outside the display range, its presence is not known by the pilot. The automation can then inform the pilot that an adaptation may be useful to achieve a more complete SA.
- *Adaptation*: the user performs the tasks on all stages of the adaptation (except maybe the execution). 'Simple adaptation gives the opportunity to the user to tailor the system to his own needs and preferences' [Dieterich et al., 1993]. For example, the user can change the brightness and contrast of the display directly. This is the same as the current adaptable interfaces.

To comply with the requirements for user-centred interface design, the user must always be offered the opportunity to overrule the adaptation. For example, if the pilot has extra information that indicates that a given TCAS advisory is false, the automatically adapted scale of the ND should be easily reverted to the original one.

## TIMING STRATEGIES OF ADAPTATION

Dieterich et al. [1993] discuss three timing strategies of adaptation: adaptation before the first use of a system, during use, and between two sessions. Only the adaptation during use is considered here. 'The adaptation can then take place continuously, on predefined junctures, after

(or before) defined functions, if a special situation appears, or on user's request' [Dieterich et al., 1993].

Continuous adaptation is not applicable to a cockpit display. It would result in a continuous change of the display, disrupting the SA building of the pilot. Examples of an adaptation requested by the user are given in the previous section. There are also situations where an adaptation may be appropriate without an explicit user request (self-adaptation), for example when starting a certain phase of the flight (adaptation to tunnel-in-the-sky during approach), or when a time-critical situation occurs that demands an immediate response of the crew (change of ND range scale during a TCAS advisory). An adaptation that is not requested by the pilot can be surprising and confusing. Therefore, these adaptations must be pre-defined and well known and trained by the crew.

## CONCLUSION

Several examples have shown the possibilities of an Adaptive Human-Machine Interface in the cockpit with different levels of adaptation and timing strategies. It is expected that a well-designed AHMI is capable of increasing flight safety, by helping the flight crew in acquiring and maintaining situation awareness. For the interface to be accepted and trusted by the pilot, two conditions have to be satisfied: 1) the pilot always has to be in control, and 2) the pilot should always be able to understand the adaptation.

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