September, 2011

Dual Operation Human-Machine Interface

Petr Krupansky
Jiri Vasek
Claudia Keinrath
Michael C. Dorneich
Larry Ball

DUAL OPERATION HUMAN-MACHINE INTERFACE

Petr KRUPANSKÝ[1] - Jiří VAŠEK[2] - Claudia KEINRATH[3] - Michael DORNEICH[4] - Larry BALL[5]

Abstract: *The paper describes a Dual Operation concept and one example of its design. The amount of information the pilot must process, already high in current Air Traffic Management (ATM) operation, will increase dramatically in the envisioned future ATM environment. New pilot functions will require new levels of automation. Thus cockpit displays must be modified in order to facilitate the pilot's future tasks and to manage the increased information available. One approach to these challenges is to adaptively modify the displays depending on current pilot tasks and situation. Simply adding functionality to current day displays has the potential to reach an unacceptable level of complexity. However, completely new displays require tremendous development and certification efforts. Therefore one of the key challenges of HMI design is how to modify current display to provide pilots with adaptive task assistance. In other words, how to offer new adaptive HMI functionality without significant modification of already proven HMI designs. This paper describes an approach to utilize the unused space on the display for showing context adaptive additional functionality without modification of the HMI management procedure with which pilots are familiar. Pilots can use the standard HMI management functions or can use context-dependent "shortcuts" offered by adaptive automation. This effectively creates two modes of operation - the Dual Operation system. This system offers a path towards the transition to more adaptive automation support, better procedural control of the aircraft, and context dependant decision making.*

Keywords: *Adaptive Human-Machine Interface, workload mitigation, task allocation*

1. INTRODUCTION

1.1 Challenge

The amount of information the pilot must process, already high in current Air Traffic Management (ATM) operation, will increase dramatically in the envisioned future ATM environment. New pilot functions will require new levels of automation. Thus cockpit displays must be modified in order to facilitate the pilot's future tasks and to manage the increased information available. One approach to these challenges is to adaptively modify the displays depending on current pilot tasks and situation. *Adaptive systems* are joint human-machine systems where automation can change its behaviour depending on changes in the user's task, mental state, or the environment in which the task is performed. These types of new adaptive automation and adaptive information management capabilities have implications for the complexity of new features to be added to existing displays. One of the key challenges of providing adaptive automation is the decision of when it is appropriate to modify the display in order to provide a pilot with adaptive task assistance. The introduction of new adaptive HMI functionality should strive to minimize modification of the current, proven HMI design. One of the problems connected with a design of new generations of HMI is a visual repositioning or modification of interface components. Such modification has the potential to introduce confusion when using the new device.

1.2 Dual Operations concept

The design of the Dual Operation concept is predicated on the philosophy that any proposed modification or changes in the display should not prevent the pilot from using the systems as usual or operational procedure requires. In adaptive systems, the additional assistance offered by automation is

[1] - Ing., PhD.; email: petr.krupansky@honeywell.com, Honeywell International, Tuřanka 100, Brno, Czech Republic
[2] - Mgr.; email: jiri.vasek@honeywell.com, Honeywell International, Tuřanka 100, Brno, Czech Republic
[3] - MSc.; email: claudia.keinrath@honeywell.com, Honeywell International, Tuřanka 100, Brno, Czech Republic
[4] - MSc., PhD.; email: michael.dorneich@honeywell.com, Honeywell Labs, Golden Valley, MN, USA
[5] - MSc.; email: Larry.Ball@honeywell.com, Honeywell International, Tempe, AZ, USA

temporary, designed to provide additional assistance only when the pilot is overloaded or cannot perform the function adequately. The Dual Operations mitigation offers support in situations where the pilot's capabilities and resources are not sufficient to meet current task demands due to factors such as time pressure, high workload, and task criticality. While the dual operations mitigation offers potential assistance, the pilot can always make a decision to follow standard operations.

2. DESIGN PHILOSOPHY

2.1 Eight levels of automation autonomy

Parasuraman, Sheridan, and Wickens [1] described a four stage model of information processing that can map to different levels of automation (the naming convention listed in brackets refers to the information processing model introduced by Boyd [4]): Information acquisition (Observe), Information analysis (Orient), Decision selection (Decide), Action implementation (Act). Proud, Hart and Morzinski [2] described how the eight levels of automation can be mapped on the four stages of processing. Detailed description of every level is beyond the scope of this paper but it is important to realize that Level 1 refers to complete human responsibility, whereas level 8 corresponds to complete computer responsibility. Each automation level is tailored to fit the tasks encompassed by the information processing stage. For example, the levels in the "Observe" group refer to gathering, monitoring, and filtering data; the levels in the "Orient" group refer to deriving a list of options through analysis, trend prediction, interpretation and integration; the levels in the "Decide" group refer to decision-making based on ranking available options; and the levels in the "Act" group refer to execution or authority to act on the chosen decision.

2.2 Task Characteristics

2.2.1 Single task

This section explains the effectiveness of a solution with respect to the level of task entropy or task ambiguity [3]. In case where there is enough time available to accomplish the task, and if there are limited number of possible solutions, depicted in as a white area of Figure 1, it is assumed that humans as well as automation will achieve the task with the same effectiveness, with respect to safety and efficiency. Area A of Figure 1 symbolizes better human performance in the face of increased task entropy, although the means to achieve this task performance is ambiguous. Area B symbolizes the situation where only a limited time is available to accomplish the task. In this situation automation would perform better, since humans are slower in task processing. Designing automation for such situations requires that it must be programmed precisely, with a clear idea of the most effective solution - there is no ambiguity how to get the task accomplished (i.e. low task entropy). Area C symbolizes the effectiveness of potential synergies of human-automation interactions. In a situation characterized with high task entropy and limited availability of time, the most effective solution would be found by a system which leverages the advantages of humans and automation. It is the goal of a good automation design. Line number 1 symbolizes the performance of a human solely responsible for task performance. Without support of automation the human task processing must start early (before point 2) in order to accomplish the task effectively and in a timely manner. Line number 3 symbolizes an example of the performance when automation is solely responsible for the task. Since automation is usually able to process tasks which are well defined with a limited number of conditions, the effectiveness of the solution found by the automation decreases with higher task entropy. However, automation can be very fast in task processing so automation can start with processing of the task later than humans (before point 4), some time before the task has to be accomplished (indicated as point 5). It should be noted that higher level of human performance (line 1) above automation performance (line 3) is just illustrative. Especially in cases when effective solution requires "Detecting signals beyond human capability" where the human is unable to solve the task at all. Line 6 symbolizes the combined performance of human and automation. The human has also longer time to actively participate on the task accomplishment (point 7). The behaviour and interaction between human and automation, is usually defined by the initial design of the system. The adaptive HMI will be applied to an already existing system. It is assumed that in the worst case the system is initially designed to behave optimal only for certain conditions and he/she can concentrate on one task after another without any disturbance [7].

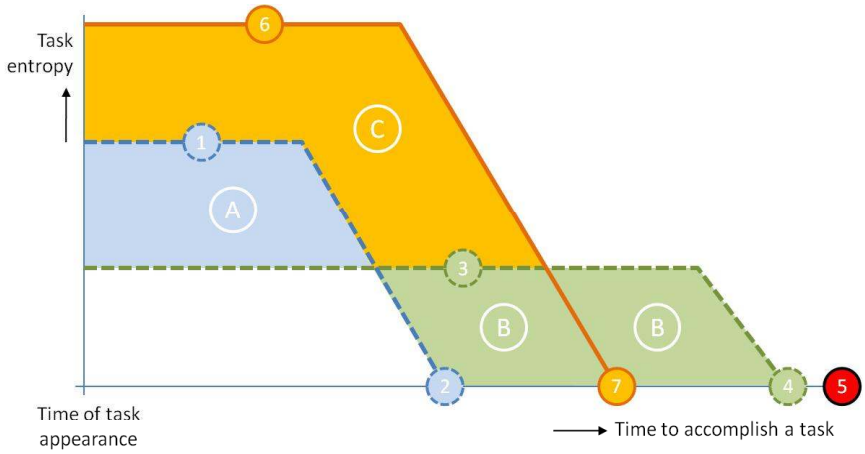

Figure 1 Single task processing

2.2.2 Task Paralelism

0 depicts the impact of multiple tasks on humans' ability to process them effectively. Points 8 and 9 represent the reduction of even task processing ability in a human-automation system. Automation can be designed in the way that multi-tasking has minimal effect on the ability of the automation to process the task. When the situation requires human processing of several tasks simultaneously, automation can try to sequence the tasks based on task priority/criticality. So when Task 1 is accomplished (Point 10), not before, the automation presents to the human information regarding the second task which triggers the processing of Task 2. Highlighting, suppressing information or re-scheduling tasks can serve as a technique helping the human to cope with multitasking [7].

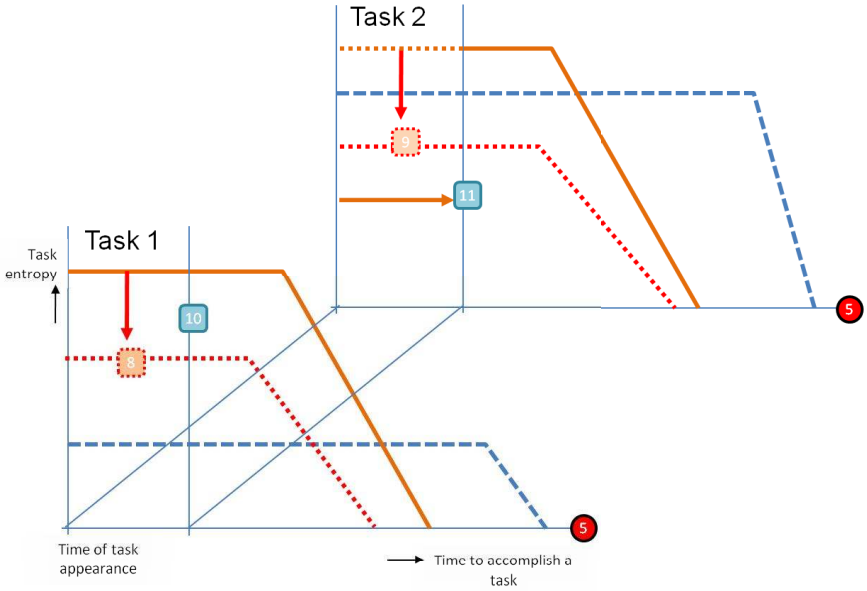

Figure 2 Processing parallel task

2.2.3 Task or Situation Certainty

The role of certainty in task or situation identification is an important aspect which must be considered in the design. The term of situation includes state of environment, human and automation. There can be shaped more precise interpretations of the principle [7]:

- Changes which lead to suppression of information or content modification have to be supported by high task or situational certainty, due to the fact that suppressing important information when processing critical tasks can have serious impacts. Often the human has ultimate responsibility, regardless of who performs the task.

- Changes which lead to an increased level of automation autonomy, in a way that the human is not involved in some functions (a suppression of human role) have to be supported also by high level of certainty.
- Changes which lead to an enhancement of the information can be supported by a lower level of certainty, because only duplication of roles is in risk, not removal human from the potentially important function in task processing.
- Changes which lead to a decreased level of automation autonomy are naturally connected with low uncertainty (low level should defined by initial design).

3. OPERATIONAL ANALYSIS

The Dual Operations concept in this example will be applied to the Ground-Aircraft datalink messages system in an aviation flight deck. Figure 3 illustrates the important steps in the processing of Ground-Aircraft datalink message in the Dual Operation concept as designed for the CAMMI project [8]. Bold arrows denote the solution path to process a datalink message request if no workload mitigation was present.

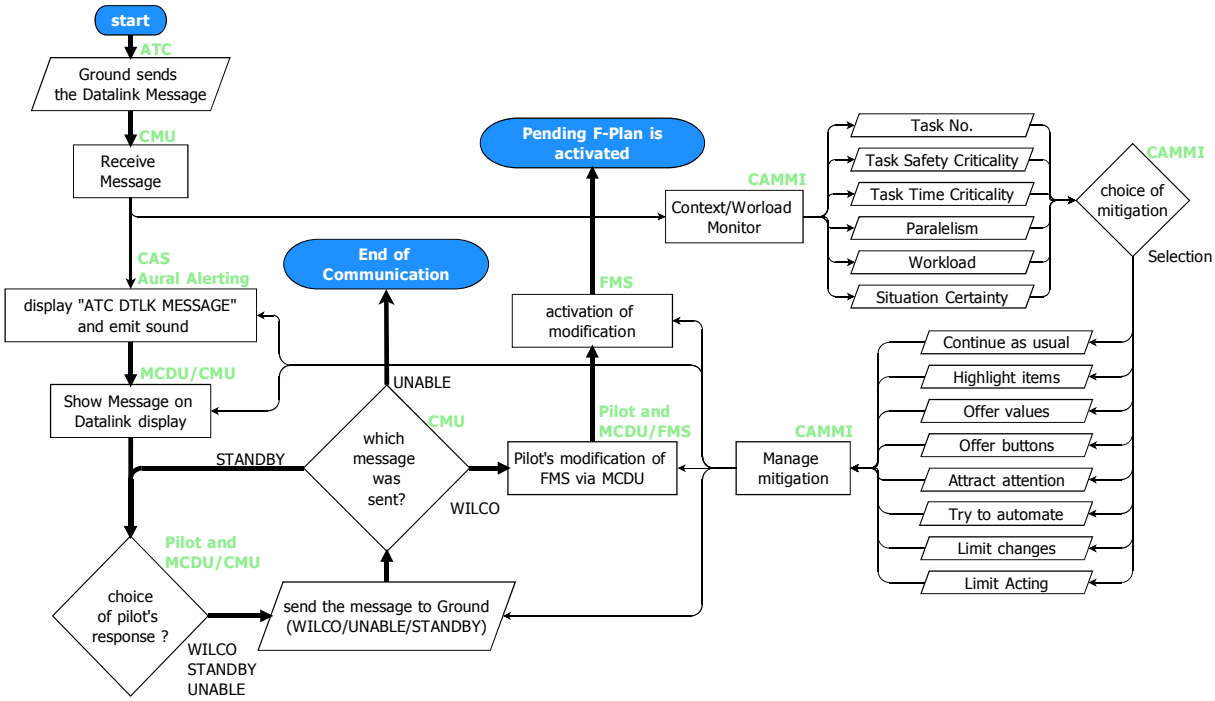

Figure 3 Operation Analysis

The figure contains the most important operations between these actors:

1. CAS – Crew Alerting System which presents crew annunciations.
2. ATC – Air Traffic Controller systems as the source of the datalink message.
3. CMU – Communication Management Unit as a device responsible for datalink communication and is usually connected with a display unit.
4. MCDU – Multifunction Display Unit as a multipurpose display unit which can be connected with CMU or FMS. The unit usually serves as text user interface.
5. FMS – Flight Management System is responsible for Flight Path planning and management, and which is usually connected with display unit.
6. Pilot – This could be the Pilot Flying or Pilot Non-Flying.
7. CAMMI encompasses the mitigation manager, context monitor, and cognitive supervisor. It is the new system to be implemented into the cockpit and includes the Dual Operation concept functionality.

From the pilot's point of view the sequence of steps to process and respond to a datalink message can be described as follows:

1. Detection of the datalink message on the CAS (e.g. the detection of an aural notification).
2. Reading datalink message on MCDU. The functionality behind MCDU is provided by Communication Management Unit (CMU).
3. Selection of appropriate response (WILCO, UNABLE, STANDBY) on the MCDU.
4. When WILCO is selected, the appropriate modification of the avionics (e.g. FMS) follows in order to apply the action requested by the datalink message. An example includes a modification requested in the Flight Plan.

The mitigations are selected on the basis of an internal logic implemented in the *Mitigation Manager* utilizing outputs from the *Context/Workolad Monitor*, which potentially has information on the following parameters:

1. *Workload* – the measurement of pilot's workload. Effect of high workload can be understood as a pilot's reduced ability to deal with task effectively and in time (e.g. line 1 in Figure 1 or lines 8, 9 in 0).
2. *Task or Situation* identifier (e.g. number, name). Difference between task and situation depends on bottom-up versus top-down perspective on activity. Sometimes it is not necessary to identify a specific task but just high level activity and their associated criticality parameters (e.g. "Push the button" versus "Aviate in Landing phase of Flight").
3. *Task or Situation Safety Criticality* – The evaluation of potential safety impact of task. The parameter drives largely the selection of task which should be in focus of pilot or automation. Tasks or situations with high Safety Criticality can be prioritized under certain circumstances.
4. *Task or Situation Time Criticality* – The evaluation of urgency of the tasks to be processed. Tasks or Situations with high Time Criticality can be prioritized under certain circumstances. In Figure 1 the Time Criticality parameter is represented by the horizontal axis.
5. *Parallelism* – The recognition of two tasks at least which occupy the pilot in the moment.
6. *Task or Situation Certainty* – The evaluation of task or situation certainty identification. Certainty of Task/Situation drives a decision from which level of automation autonomy to choose. If a Task/Situation is not certainly identified mitigation techniques that would increase automation autonomy cannot be allowed. Effect of low Task/Situation certainty can be understood as a reduced ability of automation to deal with task in time and effectively (e.g. line 3 and point 4 in Figure 1).
7. *Automatable – The* assessment if a certain task can be automated without pilot's intervention. Obviously such tasks must be supported by a high level of task/situation identification certainty.

Generally, a workload parameter indicates if any mitigation should be launched. The Criticality parameters help in a selection of concrete mitigation in time. The Certainty parameter limits automation autonomy. It should be noted that there may be multiple simultaneous tasks/situations, so the Context Monitor can produce multiple Criticality and Certainty parameters for parallel tasks/situations.

The Dual Operations concept can offer context relevant support on every step in the procedure. Such support is represented by the thin arrows in Figure 3 from the *Mitigation Controller,* which controls the implementation of the selected mitigation. The selected set of workload mitigation options include:

1. *Highlight item* – the context relevant item is highlighted in order to support the *Observe* and *Orient* functions (as defined in [7]).
2. *Offer value* – the context relevant value is displayed to support the *Orient* and *Decide* functions.
3. *Offer button* – the context relevant button is displayed to support *Decide* and *Act* functions.
4. *Attract attention* – the context relevant item is prioritized to support *Observe* and *Orient* functions.
5. *Automate processing* – some contexts allow also automated processing of datalink messages.

When two or more mitigations are used in combination, then there are some considerations on how to manage them:

1. *Limit changes* - the number of modifications is limited only to the most important few. Such a measure should be applied in cases of high Time Criticality.
2. *Limit Acting* – the mitigations supporting the *Act* function are prohibited. Such a restriction should be applied in cases of reduced certainty in the identification of the task or situation (i.e. if unsure of the situation, do not rely on the proposed automation action). This case applies in situations where mitigation acts in such a way that its sequence of actions is not fully transparent to pilot (i.e. *Automated processing* and *Offer button*).

A description of the concrete logic is beyond the scope of this paper. The choice of particular workload mitigation is almost always a logic combination of the six parameters above.

4. EXAMPLE

Figure 4 demonstrates the modified FMS frontend with Dual Ops "shortcut" buttons below the blue line as to be implemented for the CAMMI project trials [9]. The line spatially separates [7] the existing viewport above from the new features below. In addition the system can offer proposition of values beside the context relevant item (not included in the baseline test scenario). The pilot is not restricted to use the new "shortcut" buttons. The new information or buttons utilizes unused space or modifies the current HMI in such a way as to minimize the changes to the avionics. The proposed new functions are positioned in vicinity of relevant information (e.g. proposition of context correct values, highlighting of recommended items on which to focus). Any proposed new functions not related to specific displayed information/selection (but still relevant) are displayed separately. Such design creates a Dual Operation way of working in order to let the pilot choose a way of HMI management.

Figure 4 Modified MCDU

The shortcut buttons provide these functionalities:

- LOAD CPDLC – If conditions allow for Dual Ops mitigation execution then a datalink clearance is parsed and loaded as a temporary flight plan. Pilot sees all the modifications and he/she can choose to Activate or Cancel the temporary Flight plan. The activity connected with manual programming of FMS is transferred from pilot to FMS Mitigation Controller.
- ACT+WILCO – FMS Mitigation Controller processes the same steps as in case of LOAD CPDLC. In addition an activation of the temporary flight plan is executed as well as the sending of WILCO response to ATC. The CPDLC message becomes CLOSED.
- CANCEL+UNABLE - FMS Mitigation Controller removes (or does not insert) the temporary flight plan and orders the CPDLC message control to send an UNABLE response to the ATC. The CPDLC message becomes CLOSED.

- "270" button - If conditions allow Dual Ops mitigation execution then a datalink clearance is parsed and part of clearances can be offered as a shortcut button in the vicinity of relevant item. In this way pilot can insert only a particular item instead of whole datalink clearance. The activity connected with manual programming of the FMS is transferred from the pilot to the FMS Mitigation Controller.

Several variants of adaptive behaviour can occure:

- Some of the buttons are flashing – Such behavior happens in situations when management of datalink clearance is more safety & time critical task than an on-going task.
- Only the most appropriate buttons appear – Such behavior happens in situations when management of datalink clearance is more time critical than an on-going task.
- Only LOAD CPDLC button is visible – If a task identification is uncertain then the mitigations which includes acting are forbidden (i.e. Activate, Cancel actions).

It should be noted that the label of the shortcut buttons can vary based on the context of the CPDLC message (e.g. some messages require only a ROGER response).

5. CONCLUSION

The Dual Operation concept was presented. Obviously the concept and design philosophy are not limited only to the presented example. Limited implementation and test of functionality is a subject of the present phase of the CAMMI project.

This research has been performed with support from the EU ARTEMIS JU project CAMMI SP-8 - GA No.: 100008. The opinions expressed herein are those of the authors and do not necessarily reflect the views of the EU ARTEMIS JU. A very special recognition needs to be given to Michal Chytil for his extensive effort in developing of Dual Ops prototype.

REFERENCES

1. Parasuraman, R., Sheridan, T. B., & Wickens, C. D. (2000, May). A Model for Types and Levels of Human Interaction with Automation. IEEE Transactions on systems, man, and cybernetics-part A: Systems and humans , 30 (3).
2. Proud, R. W., Hart, J. J., & Morzinski, R. B. (2003). Methods for Determining the Level of Autonomy to Design into a Human Spaceflight Vehicle: A Function Specific Approach. Conference on Performance Metric for Intelligent Systems.
3. Sheridan, T. B., & Verplank, W. (1978). Human and Computer Control of Undersea Teleoperators. Cambridge, MA: Man-Machine Systems Laboratory, Department of Mechanical Engineering, MIT.
4. Boyd, J.R. (1995). "The Essence of Winning and Losing". Presentation presented 28 June 1995. Available online at:
5. http://www.chetrichards.com/modern_business_strategy/boyd/essence/eowl_frameset.htm
6. Anderson, J. R. (2005). Cognitive psychology and its implications (6th ed.). New York, NY.: Worth Publishers.
7. CAMMI Consortium: D2.2.1- EFIS: Requirements and Mitigation Actions Report, Artemis Joint Undertaking, 2010
8. CAMMI Consortium: D3.1.1- EFIS: Requirements and strategies report, Artemis Joint Undertaking, 2010
9. CAMMI Consortium: D4.1.1- EFIS: MMI Prototype report, Artemis Joint Undertaking, 2011

Reviewer: Prof. John A. Wise, PhD., email: JohnWise@alumni.Pitt.edu, Ormond Beach, FL, USA