Human-Centered Automation for improving Situation Awareness in the Fighter Aircraft Domain

Tove Helldin and Göran Falkman

Abstract—Advancements in technology and the need for improving the pilots’ working situations have stimulated the growth of automated functions within the fighter aircraft domain. Functions that aid the pilots perform their tasks and to make decisions fast in an often rapidly changing environment have been introduced with the ultimate aim of easing the pilots’ workloads and improving their situation awareness. However, both positive and negative effects of automating pilots’ tasks have been documented, such as decreased workload and skill degradation, and it has been acknowledged that it is important to consider the needs of the human operator when designing automated functions. Human-Centred Automation (HCA) has been suggested as an approach for designing automated systems that brings forward the positive effects of automation. However, how to apply the concept of HCA in light of the specific prerequisites and demands of the modern fighter aircraft domain has not been fully investigated. This paper presents the results from interviews made together with fighter aircraft system developers, where the concept of HCA was investigated. Their opinions of the applicability of the concept of HCA within the fighter aircraft domain is presented as well as their thoughts about identified HCA guidelines in relation to the proposed support system. Conclusions drawn from the study are that HCA is indeed an important concept to consider within the domain as well as that the proposed guidelines could be of great use during the design process. Additionally, insight into how to design automated support systems with the concept of HCA in mind is given.

Index Terms—Human-centered automation, fighter aircraft, system development, guidelines, situation awareness.

1. INTRODUCTION

The fast-paced technological development the past decades has resulted in more and more automation in several domains. Today, there are cars that aid their drivers park as well as surveillance systems, for example within the nuclear power domain, that aid their operators detect processing faults. Within the fighter aircraft domain, several research programs have been conducted since the 1980’s with the aim of improving the pilots’ execution of their tasks through the introduction of different automatic support system (see for instance [1-5]). The future of fighter aircraft is foreseen to involve even more automated technologies due to the increasing demands put on the pilots to cooperate in larger teams (for example during international missions) as well as to create a good situational picture of the environment despite the ever increasing amounts of data provided by more advanced sensors (see for instance [6]).

The introduction of automated technologies has often been motivated by the anticipated positive effects upon operator workload and situation awareness. However, negative effects of automation have also been reported, such as skill degradation and complacent behaviour (see for instance [7]). Thus, it has been acknowledged that the automated technologies must be developed with the human operator in mind. One approach is to make the automation human-centred. According to [8], Human-Centred Automation (HCA) is an approach to create an environment in which humans and machines collaborate cooperatively in order to reach stated objectives. To achieve such automation, it is important that careful investigations are performed regarding which tasks to automate and at which level of automation that these tasks should be implemented at. Recent research within HCA has resulted in several guidelines that are expected to aid developers of automated systems create support that suit their intended users (see for example [9-12]). Furthermore, results of empirical investigations within the fighter aircraft domain have added to this pool of guidelines domain specific HCA recommendations (see [13]). However, how to apply these guidelines when developing future tactical support systems has not been investigated.

Erlandsson, Niklasson, Nordlund and Warston [14] have proposed a support system aiding the pilots by assessing their chances of survival when flying a certain route. The authors of this paper argue that such system could provide individual and...
team strategic guidance of how to act in threatening situations, aid them with creating and maintaining a better awareness of the situation and to make better decisions fast. This paper presents the results from interviews made together with support system developers at Saab Aeronautics in Linköping, Sweden, where the concept of HCA was investigated. Their opinions of the applicability of the concept of HCA within the fighter aircraft domain is presented as well as their thoughts about identified HCA guidelines in relation to the support system proposed by [14]. The results from this study provide insight into the challenges that developers of such support systems are faced with as well as how the concept of HCA could guide their work.

II. THE NEED FOR AUTOMATIC SUPPORT IN THE FIGHTER AIRCRAFT DOMAIN

Within the fighter aircraft domain, the pilots often have to perform fast-paced actions and make decisions in the presence of huge amounts of data. This data is collected from different sensors, databases, members of the flight team etc. and might be uncertain and sometimes even contradictory. Wrong or late decisions might lead to fatal consequences, which further aggravates the often already stressful situations and high cognitive and physical workloads of the pilots. To create and maintain good individual and team situation awareness of the situation is of utmost importance for the pilots to be able to fly safely, accomplish the goal of the mission and to survive potential battles. Constant updates of the pilots’ situational pictures must be performed through frequent deliveries of data presented on the displays and through the different means of communication between the members of the team.

Several automatic support systems have been implemented in modern fighter aircraft so as to aid the pilots perform their tasks and to improve their situation awareness. For example, there are support systems aiding the pilots to navigate, start and land the aircraft as well as to distribute information within a team. Research programs such as the US Pilot’s Associate, the French Copilote Electronique and the Dutch POWER project all focused on developing decision support for fighter pilots which would aid them perform their tasks during a mission (see for instance [1, 2, 4]). However, these programs focused mainly on systems that support single pilots, and not the team as a whole. In [15], the need for developing a support system that aids a team of pilots reach their objectives and that supports their individual and team situational picture is highlighted, see Figure 1. Such system could automatically aid the pilots with the four tasks proposed by Parasuraman et al. [11], i.e. the acquisition of information from the surroundings, an analysis of this information, the generation of possible decisions and actions based on the analysis as well as the implementation of selected action(s).

In threatening situations, the role of the support systems becomes even more central since it is often during such situations that the pilots need help with assessing the situation and to allocate tasks to the system so as to accomplish the goal of the mission. However, it is argued in this paper that the introduction of new and better sensors and weapons, new warfare strategies and the establishment of larger teams during international missions have resulted in a need for implementing additional support systems to be used by the pilots. We anticipate that the system proposed in [14] is able to support the pilots create and maintain individual and team situation awareness as well as to improve the pilots’ decision making processes during flight. This support system is expected to gather information from the different data sources in the surroundings and, based on this information, estimate the pilots’ chances of survival when flying a given route. Such system could aid the pilots generate alternative routes based on the available information if, for example, the current route is considered to be too dangerous, as well as to plan their usage of countermeasures during a mission.

![Fig. 1. A support system is expected to aid the pilots balance the three objectives of flight safety, combat survival and mission accomplishment (adapted after [15]).](image-url)

It is of utmost importance that the implemented automatic functions appropriately support the pilots. To aid system developers design such system, we argue that the concept of HCA has to be taken into account during the design process. To do that, we further argue that the developers must consider three important issues: 1) trust in automation, 2) suitable task allocation and 3) appropriate levels of automation. Especially, we argue that domain specific guidelines can be of great use for developers of automatic support systems. These issues will be the focus of the next section.

III. HCA CHARACTERISTICS

To aid developers of automated functions design with the concept of HCA in mind, i.e. automation that collaborates with its users instead of replacing them, researchers have acknowledged the importance of establishing a good trust relationship between the automation and its operators, that careful analyses must be performed regarding the task allocation between the operators and the support systems as well as that these tasks must be implemented at an appropriate level of automation (LOA) (see for example [9-12, 16, 17]).
Trust has been defined as “the extent to which a user is confident in, and willing to act on the basis of the recommendations, actions and decisions of an artificially intelligent decision aid” [18] (p.1) and is regarded as an important component for a successful human-machine relationship. However, the user’s trust in automated functions must correctly reflect the capability of the automation. If the automation is faulty, a too high level of trust might result in automation faults not being detected, while a too low level of trust might lead to the absence of the anticipated positive effects of introducing the automation (such as better situation awareness, lower workload etc.) (see for example [7, 19, 20]).

To establish a good trust relationship between the user and the automated functions it is important that the user is involved in the automation process through making a detailed analysis of the task allocation to implement (what should be automated and what should be done manually) as well as that the automated tasks are implemented at an appropriate automation level [21]. According to [22], there are ten levels of automation – ranging from low automation (manual control) to high automation (full automation) and which level to implement must be carefully analysed together with the end users.

To further support developers of support systems, it has been argued that guidelines can be of use (see for example [23]). Table 1 below presents a set of domain relevant human-centred automation guidelines that are expected to aid system developers of modern fighter aircraft support systems design ([13]).

<table>
<thead>
<tr>
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<th>HCA GUIDELINES WITH APPLICABILITY TO THE FIGHTER AIRCRAFT DOMAIN</th>
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<tbody>
<tr>
<td>1</td>
<td>Provide access to raw data [9].</td>
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<tr>
<td></td>
<td>• Provide access to raw data during training and at debriefing.</td>
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<tr>
<td>2</td>
<td>Provide means to indicate to the user that data is missing, incomplete, unreliable or invalid [9].</td>
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<td></td>
<td>• Present how reliable the results from the threat evaluation are as well as what factors have influenced the evaluation.</td>
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<td>3</td>
<td>Make clear to the user the purpose of the automation [9].</td>
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<td></td>
<td>• Do not automate tasks that are best performed by the pilots – this might lead to out-of-the-loop performance problems.</td>
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<td>4</td>
<td>Reveal the rules and algorithms used by the automation, and if possible, keep the algorithms simple [9].</td>
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<td>• Full understanding of the underlying algorithms is not required; however a limited understanding might suffice to ensure that the pilots understand why certain recommendations have been posed.</td>
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<td>5</td>
<td>Show the source of automation failure [9].</td>
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<tr>
<td></td>
<td>• Reveal sources of automation failure due to uncertain data.</td>
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<tr>
<td>6</td>
<td>Provide relevant feedback [9].</td>
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<td></td>
<td>• Inform the pilot of the tasks carried out by the automated functions.</td>
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<td>7</td>
<td>If possible, make the automation cooperative rather than replacing the operator [10].</td>
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<td></td>
<td>• Cooperation between the support system and the pilot is of great importance, however depending on the specific tasks.</td>
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<td>8</td>
<td>Carefully design the automation with appropriate automation levels in mind [12].</td>
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<td></td>
<td>• Appropriate automation levels depend on the specific task in mind, the current situation in terms of workload etc.</td>
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<tr>
<td>9</td>
<td>Provide automatic support to enhance information and decision distribution within a team [13].</td>
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<tr>
<td></td>
<td>• Let the team leader decide upon appropriate actions that are then automatically distributed within the team.</td>
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<tr>
<td>10</td>
<td>Provide automatic support that updates the individual and team situational pictures [13].</td>
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<tr>
<td></td>
<td>• Relevant information should automatically be distributed within the team.</td>
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These guidelines have been identified from a literature study performed within the domain as well as from a survey performed with Swedish fighter pilots (see [13]). However, how to apply these during the system development process within the modern fighter aircraft domain has, to our knowledge, not been investigated. Thus, a study has been performed to investigate system developers’ views upon important HCA characteristics within the domain as well as in relation to the proposed support system (as presented in section II). Their opinions regarding the identified HCA guidelines have been collected as well as if the guidelines could be of use to them when designing human-centred (or “pilot-centred”) automatic support systems. The results from this study are presented in the following section.

IV. THE STUDY

To investigate the state of the art of HCA within the modern fighter aircraft industry, interviews with six system developers at a fighter aircraft development company, Saab Aeronautics in Sweden, were carried out. The interviewees were human-machine interface developers who had experience of conducting design projects within the domain. During these interviews the participants had to answer questions divided into six themes: 1) the role of HCA in the fighter aircraft domain, 2) important HCA characteristics, 3) domain specific HCA guidelines, 4) the use of guidelines, 5) HCA during the development process and 6) HCA guidelines in relation to the proposed support system. Developers at the human-machine-interface (HMI) department were selected due to the close relationship between the implementation of HCA functions and its presentation or feedback to the end users. The interviews were carried out in a semi-structured way so as to
follow a focus, but at the same time allow for fruitful discussions to take place. The interviewees were informed of the purpose of the study as well as how the results were to be used. The results from the interviews were provided to the interviewees so as to avoid possible misunderstandings as well as to offer them a second chance to express their opinions.

A. The role of HCA in the fighter aircraft domain

The developers interviewed were not acquainted with the concept of HCA (as defined by [8]), but argued that it is an important concept to consider within the fighter aircraft domain due to the existing and increasing number of automated support functions implemented as well as the characteristics of the domain such as the fast-paced tempo, time-pressure and the often high workload. They further argued that despite that they had not been presented with the exact definition before, the central ideas of HCA are indeed considered during the development process. They further claimed that despite the strong unmanned aerial vehicle (UAV) development, it is not likely that the pilots will be replaced and, consequently, it is very important to keep the pilots in the decision and action loop. To achieve this, they further claimed that it is very important to make the automation cooperative.

To make the automation suitable for the pilots was also considered crucial. Fighter pilots in general like to be in control of the aircraft they are flying, thus careful investigations are performed jointly with support system developers and pilots so as to design systems that provide appropriate support. A further challenge mentioned during the interviews was to implement well-designed automated functions that the pilots can trust, while at the same time making use of the latest technologies which make more tasks possible to automate.

B. Important HCA characteristics

The interviewees argued that it is very important that the automated system is not perceived as a “black box” where the pilot has no knowledge of how the system works. Instead, they argued that it should be easy for the pilots to create and maintain a mental model of the system. This is often achieved through referring to automated functions in terms of their flight mode relationships. The pilots are extensively trained to handle the different modes of the aircraft which all imply a set of automatic functions available to the pilots. As such “automation surprises” are kept to a minimum and the pilots are better able to trust that the system performs its allocated tasks. The interviewees further argued that to make the automated functions similar in behaviour and output (i.e. to make the automation consistent) within the different flight modes would aid the pilots create a good mental picture of them. In the same spirit, the interviewees argued that automated functions must be looked upon in their larger contexts, i.e. an analysis must be performed so as to get an overview of which systems are affected by a specific set of functions, in which modes these functions should be made available etc. As such, the pilots will be aided with building up a coherent picture of how their support systems are designed and how they function.

Relevant feedback from the system was also considered an important HCA characteristic, however to a certain level. To make the support system transparent enough to the pilots as well as at the same time keep the information flow at a reasonable level was considered a difficult balancing act. Thus, the interviewees argued that the pilots do not have to know everything about the system or every task it performs, and that a simple mental model of how the system works should be sufficient. Therefore, complicated calculations need not be presented to the pilots. The interviewees also acknowledged the fact that to present the outcomes of the automated functions is a challenging task.

To avoid “automation surprises” the interviewees argued that it is better if the automation is initiated by the pilots. However, there is always a risk of “loosing” the pilots, indicating that it is very central that the system informs the pilots of its commitments. Which tasks to allocate to the system or to the pilots is situation dependent and it is very important that careful investigations are performed regarding this allocation as well as that the pilots are able to train during different situations so as to avoid automation surprises. Furthermore, to make the automation cooperative was looked upon as a prerequisite for making the pilots trust the system.

C. Domain specific HCA guidelines

The interviewees were presented with the guidelines in Table 1 and a discussion of their implications within the domain was conducted. The developers interviewed were not acquainted with the HCA guidelines but argued that they consider many of them during the design process. However, a majority of the HMI developers argued that guideline 1 (see Table 1) concerning presenting raw data to the pilots should not be followed in this domain since this would imply too much information to present to the pilots that would not improve the quality of the decisions or tasks that they perform. The interviewees did not think that the pilots would want to or have time to perform cross-checks if the system produces correct results based on the raw data used as input to the system. As one of the participants stated – “this is why we have support systems – so that the pilots do not have to analyse this data”.

Furthermore, to display the often complex and multidimensional data from, for example, sensors would be difficult to perform on two-dimensional displays (which is referred to as the “Human-Computer Interface Bottleneck”, see for example [24, 25]). However, to display information about what the system is doing and why was considered important, especially before a mission and during training. Though, the interviewees acknowledged that there is a difficult balancing act between having a transparent system which informs the pilots of its undertakings and inner workings and having a system that eases the pilots’ workloads by reducing the amount of information on the screens that the pilots have to process.

To reveal the rules behind the support system (as suggested by the fourth guideline) was considered important so that the
pilot understands what the system can do, but not with too much detail. To reveal the algorithms behind the workings of the system was considered to be too difficult for the pilots to understand, as well as that a more general understanding would be enough in order for them to use the system and trust it appropriately. It was further argued that to know at which level of automation to implement a function at (i.e. guideline 8) is difficult and that one has to analyse what the different levels mean in the specific situation (i.e. which support systems that are involved etc.).

Another guideline that received strong approval was the second guideline, i.e. to indicate to the user if data is missing or incomplete as well as when the automation no longer can be trusted. To indicate which functions/systems that are no longer automated and what the pilot has to do manually must be explicitly presented. This is also in line with the fifth and sixth guidelines, i.e. to make the source of automation failure explicit as well as to provide relevant feedback to the pilots. Additionally, the last two guidelines (guidelines 9 – 10) regarding information distribution within a team and to provide support for the pilots’ creation of their situational pictures, were regarded as very important for mission success during a whole scenario.

A general conclusion drawn from the discussions regarding the HCA guidelines is that automated functions should concentrate on aiding pilots perform their tasks, i.e. focus should be on automating what the pilots want to achieve. Thus the guideline advocating that the automation should be cooperative was strongly accepted. However, as previously argued, the interviewees thought that the automation should be pilot initiated, for example by changing the flight mode. In the same spirit, the HMI developers argued that it should be easy for the pilots to turn the automation on/off when desired, for example if they do not longer trust the system. They further argued that actions performed manually by pilots should be given a higher prioritization than automated actions in order to make sure that the pilots are the ones in control of the aircraft.

D. The use of guidelines

The participants were also asked if they have experience of using design guidelines during the development process. A majority of the participants answered that guidelines are used during the development process and that these guidelines stem from a heritage of previous development processes, pilot- and customer experiences as well as usability and HMI research. To use guidelines that have been developed with the intended end users in mind was considered important as well as that they are frequently updated in pace with new technological advancements.

The participants in the study argued that they believe that the guidelines presented in Table 1 (see Section III) would be useful for them during a development process but that more details regarding how to incorporate them into the design process must be added. The interviewees argued that the guidelines could be used as a checklist of issues that have to be considered when designing automated functions and, as such, become less dependent on extensive pilot tests. Furthermore, the use of such guidelines could aid them to think more about automation issues while designing, such as how automated functions should behave together. However, for each specific situation, an investigation of which guidelines that are relevant for the specific function in mind must be performed.

E. HCA during the system development process

All of the participants said that they do not explicitly think in terms of HCA when developing, however that many of the guidelines presented to them are implicitly a part of the development process. For example, the interviewees argued that they perform evaluations together with pilots where the proposed functions are analysed, which aids them to design the functions in a “pilot-centred” way. The interviewees all argued that they constantly have in mind that the purpose of the design and implementation of new support systems is to aid fighter pilots perform their tasks and to ease their workloads. This aspect is considered to become even more central in the future due to the current and expected escalating introduction of automated functions in the fighter aircraft domain, thus deeper analyses and tests must be performed so as to develop systems that are well suited for their users. The interviewees argued that the HCA focus should be especially prevalent during the pre-study phases of the development process in order to carefully investigate which tasks that should be automated and which sub-systems that will be affected by this automation. Furthermore, to analyse which functions that will be used together and to make them consistent in their behaviour and outcomes, was considered important.

F. HCA guidelines in relation to the proposed support system

A first implementation of the proposed support system and an explanation of its function were presented to the developers (for secrecy issues, details about this system cannot be presented, however see Section II and [14] for some information about this system). Based on their experiences of developing automated functions within the domain as well as in relation to the concept of human-centred automation, the developers were asked to make a first evaluation of the support system.

To make the automated functions of the prototype “pilot-centred”, the developers argued that the survivability function and its presentation should be possible to turn on/off so that the pilots can choose whether to use it or not. Preferably, they further argued that the system should generate a set of possible actions to perform when the threatening situation has been deemed to be too dangerous. The system could generate a set of alternative routes, but which all lead back to the original route so that less re-planning has to be performed. To let the pilots add a waypoint to the route themselves was also considered to make the automation more “pilot-centred” through implementing collaborative automation (as guideline 7 advocates).

The interviewees all argued that it is of utmost importance to perform evaluations of the support system together with fighter pilots so as to, for example, investigate which feedback that is considered relevant (as guideline 6 advocates) as well as which raw data that could be of use to the pilots. Furthermore,
to involve the pilots early in the development process would give them a chance to be able to influence the tasks allocation of the proposed automated functions. Additionally, if the pilots have been involved during the development process, and know how the system works, they might trust the system more.

V. DISCUSSION

The results from the interviews indicate that a majority of the HCA guidelines listed in Table 1 (see Section III) are indeed implicitly considered during the development process. However, it was the general opinion of all the participants that it is important to limit the amount of raw data presented to the pilots, since this can overwhelm them with information that will not positively influence their decision making processes. Furthermore, to put more focus on displaying the quality of the data used was considered extremely important so as to make sure that the pilots have a good base of information to base their decisions on.

To have HCA characteristics in mind during the design process was considered very important so as to be able to develop automated functions that are well-suited for the pilots. It was further argued that the developers should especially focus on the concept of HCA during the pre-study phases of the design process so as to carefully investigate which tasks that should be automated as well as which sub-systems that will be affected by these automated tasks. By doing so, it is expected that the developers will be able to design automated functions that appropriately and reliably will support their operators. To use the list of guidelines presented in Table 1 as a checklist of what to consider during the development process was predicted to be helpful for them to explicitly incorporate important HCA issues during the design process. However, how to incorporate these guidelines into the development process must be further investigated and a deeper investigation of their exact implications in different scenarios must be performed.

It was further stressed that “automation surprises” should be avoided through making sure that the pilots are extensively trained to use the automated functions as well as to associate these functions with the appropriate flight modes incorporated into the aircraft. Useful feedback was also given concerning how to make the proof-of-concept prototype more pilot-centered, such as to indicate the trustworthiness of the results from the survivability calculations as well as to make the automation more cooperative by letting the pilots interact with the system to generate alternative routes with a better estimated survivability rate. A summary of the findings are presented in Table 2 below.

The interviews performed are the first of many interviews that need to be performed to investigate the state of the art of HCA within the fighter aircraft domain. The proposed support system must be evaluated together with fighter pilots so as to receive the actual end users opinions of the proposed functionality and its automation design. Additionally, interviews with additional developers would further increase our knowledge of how to incorporate the concept of HCA in the system development process in the fighter aircraft domain.

Furthermore, similar studies must be performed at other companies within the domain so as to receive a better picture of the state of the art of “pilot-centred automation”. Such interviews are expected to further increase our knowledge of the status and implications of HCA within the modern fighter aircraft industry.

**TABLE I**

A SUMMARY OF THE INTERVIEW FINDINGS

| Fighter aircraft support system designers should strive to limit the amount of raw data presented to the pilots. |
| It is of outmost importance to display the quality of the data to the pilots. |
| Much focus on the concept of HCA should be put during the pre-study phase of the development process. |
| Fighter aircraft support system designers could use the guidelines (presented in Table 1) as a checklist so as to explicitly consider the concept of HCA during the development process. |
| How to incorporate the HCA guidelines during the development process must be further investigated. |
| To avoid “automation surprises” support system designers should associate automated functions with appropriate flight modes. Additionally, the pilots must be extensively trained to use the automated functions. |

VI. CONCLUSION AND FUTURE WORK

To consider the concept of HCA within the fighter aircraft domain is important so as to be able to create support systems that provide the needed support for the pilots. Its role within the domain is foreseen to become even more explicit due to the ever increasing implementation of automated systems within the domain, aiding the pilots dealing with the new technologies available and the new warfare strategies. Several guidelines of how to achieve human-centred automation have been proposed and the developers of automatic support systems must analyse which of these are important in the given situation as well as to possibly use these as a checklist during the design process.

Future work includes further interviews with system developers within the domain who work with designing and implementing decision support functions. These interviews are anticipated to provide more knowledge of how to apply the proposed guidelines within the fighter aircraft domain. Furthermore, a first evaluation of the proof-of-concept prototype must be performed so as to involve the pilots in the development process as well as to investigate the implications of the listed guidelines in relation to the proposed system.

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