The Next Generation Cockpit: Requirements of Fighter Pilots in a Highly Automated Environment

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Abstract: This study aims to explore the opinions of fighter pilots regarding past, current, and future Human-Machine-Interfaces. The first motivation of this study is to identify aspects of different interfaces within a fighter cockpit and the collaboration between unmanned platforms influencing the perceived performance of pilots. A second motivation is to create a list of requirements for future interface functionalities to narrow down the vast range of possible State-of-the-Art inventions to a few which, according to pilots, are of particularly good or bad use. Semi-structured interviews were conducted and analysed. For the analysis, a coding method was applied based on the 'Mayring'-technique. Following this process, the raw data in form of interview transcripts were cleaned first and, subsequently, codes were created. From these codes, categories were defined and, on basis of the frequency of occurrence, main categories were filtered out. The main categories of this study are 'Information sources', 'Risks of new technologies', 'Interaction with unmanned platforms', and 'Adaptive automation'. Some variation was found within the category of 'Interaction with unmanned platforms', these are mainly expressed through varying preferences of communication channels. The other three categories show a lot of similarities between opinions of pilots. Most relevant codes are concerned with over-engineering and the use of automation to appropriately support pilots in their tasks. In conclusion, this study provides a mostly clear picture of subjective opinions of pilots regarding modern cockpits and the application of new technological developments for the future, thereby providing valuable input for the requirements engineering of the next generation cockpit.

1 INTRODUCTION

This explorative study aims to establish requirements according to fighter pilots for the next generation fighter (NGF) and is conducted in light of the current European 'Future Combat Air System' (FCAS) program. The aim of this program is the development of the 'Next Generation Weapon System' (NGWS), which is characterized by the development of a 6th generation piloted fighter working together with unmanned aerial vehicles (UAVs) and being connected to various systems of different domains (Airbus, n.d.). The main feature of this so called 'system of systems' is the switch from manned platforms flying in formation to a (single manned-) collaboration of different weapon systems in different domains. The premises of this structural change are the facilitation of an information superiority, cooperative mission execution, adjustment to a highly dynamic operative environment, and a flexibly adaptability towards an ever-changing capability profile (ESG, n.d.).

The development of this 'Next Generation Fighter' (NGF) is accompanied by multiple challenges which demand an overhaul of the last generation's cockpit to fit the new requirements. Critical for these requirements is that the new technological functions are enabled while ensuring successful incorporation of the human component.

To offer a common understanding about how technology has evolved over the last decades as well as to present the state-of-the-art cockpit technology (5th generation), a brief summary of the development of cockpit technology is presented. One of the most prominent changes is the evolution of analogue indicators to digital displays. Moreover, technological improvements within the cockpit, including avionic systems and primary/secondary control elements, have facilitated increasingly more integrated and automated 'Human-Machine Interfaces and Interactions' (HMI²) both in civil and military aviation (Lim et al., 2018). This change of the HMIs becomes apparent when looking at cockpit interfaces from first-generation fighters like the F-86

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Sabre or the Mikoyan-Gurevich Mig-15 compared to cockpit interfaces of a 5th generation fighter like the F-22 Raptor or F-35 Lightning (Martinic, 2015).

However, any progress in the field of HMI development likely has a significant impact on the user, i.e. the pilot, who has to perform operations within this local environment, i.e. the cockpit (Ismayilov, 2022). This became first clear during World War II when discipline practitioners observed poorly designed systems which were unsafe and difficult to operate. Especially in the aviation domain seemingly random failures and crashes occurred (Air Force, n.d.; Keebler & Fausett, 2023). Finally, understanding how users function within their respective system and how the design of a system, its controls, and the surrounding environment affect safety and performance became the aim of research (Keebler & Fausett, 2023). Thus, the scientific field of Human Factors Engineering (HFE) emerged.

Various standards emphasise the involvement of users in the design process to facilitate understanding of how the user functions within the respective system. The ANSI/HFES 400-2021 standard, for example, describes the development process of a technology with a human component. Here, it is essential to include users throughout the entire design process starting with learning as much as possible about all the varieties of users who may potentially be involved, their capabilities, limitations, performance, and behaviour within the human-machine system. In later stages, the standard describes the relevance of including the right sample population for prototype testing as well as continuing the observation of user performance with the technology after being implemented in the real world (Human Factors and Ergonomics Society, 2021). Another topic-relevant document is the NATO standard for designing unmanned aircraft systems which states that it is essential for the effectiveness and safety that the human is fully integrated into the development process starting at the system conception level (NATO Standardization Office, 2022).

In accordance with the statements about the importance of user inclusion and overall HFE processes, this study aims at gathering relevant information from fighter pilots for the design of the 6th generation fighter cockpit. In more detail, the aim is to establish requirements for the new cockpit based on (1) what experiences pilots had with interfaces they were familiar with and (2) which expectations pilots have regarding the main additions of the NGF (i.e. the inclusion of UAVs, the thusly increased adaptive automation technology as well as state-of-the-art interaction technologies).

2 METHODS

2.1 Participants

For this study, a total of twelve participants were interviewed. Due to the focus on military aviation in our study, only fighter pilots were used as sample group. Eight participants had the job of flight pilots (i.e. 'front seater') whereas four participants served as weapon systems officers (i.e. 'back seater'). The following aircraft have been flown by our participants: F4, F18, Eurofighter, Tornado IDS & ECR, and Alpha Jet. Due to one missing signed consent form, only eleven interview transcripts were used in the analysis.

2.2 Materials

In this study, a semi-structured interview was used as data collection method (see Appendix A). The standard app for voice memos on the iPhone SE 2020 was used to record the interview. A coding guideline, based on the analysis method of Mayring, (Mayring, 2022) was used to set the information gathered from the interviews into a meaningful context (see Appendix B).

2.3 Procedure & Analysis

In this qualitative study the phenomenological research method was used since the goal was to capture multiple subjective perspectives/experiences to the topic in question. For the data collection, semi-structured one-to-one expert interviews were conducted and the intelligent verbatim technique was used for the transcription process.

A thematic analysis was conducted by applying the summarizing structured evaluation process of Mayring to identify patterns/themes within the data relevant to the research question of this study. The respective codes were created using a hybrid approach of deductive and inductive techniques. Hereby, the categories were created deductively based on main aspects of the FCAS program whereas sub-categories were coded inductively from the data.

3 RESULTS

A total of four deductively created categories were formed: (1) Opinions on HMIs / information sources within the cockpit, (2) Perceived risks of new technologies in the NGF, (3) Interaction with UAVs as part of future tactical and strategic mission execution, and (4) Requirements for adaptive automation functionality envisioned as part of the NGF. Within each category, sets of sub-categories were formed inductively by analysing the interview transcripts. The exact contents of each sub-category are described in the discussion section of this study.

The first set of sub-categories allocated to the category 'Opinions on HMIs/information sources within the cockpit' are listed in Table 1. For the sub-category 'Information presentation', topics like central layout and opinions regarding multimodal information presentation are included. The sub-category 'Arrangement of control elements' includes usability features (i.e. visibility and accessibility), safety features, and personalisation. The sub-category 'Multimodal controlling' includes opinions expressed towards interaction elements like touch, gestures, and button types, as well as feedback requirements. The sub-category 'General HMI requirements' includes user requirements regarding the general HMI design and user friendliness aspects.

Within the sub-categories 'Information presentation' and 'Multimodal controlling', respectively, topics like hard keys vs. touch and centralized information depiction were of most relevance during interviews.

Table 1: Opinions on HMIs/information sources within the cockpit.

Category	Sub-category
Opinions on HMIs/Information sources within the cockpit	Information presentation
	Arrangement of control elements
	Multimodal controlling
	General HMI requirements

The category 'Perceived risks of new technology in the NGF' has a total of five sub-categories as listed in Table 2. The sub-category 'Over-engineering' includes the concern of pilots to not be integrated enough in the design process, resulting in incorrect information depiction (regarding timing and location) and inclusion of unnecessary gimmicks. The sub-category 'Individual differences among pilots' includes the concern of pilots to not be included in the correct manner, i.e. that individual differences, and thus requirements, of different pilot roles might be overlooked. The sub-category 'Workload' includes concerns of pilots related to being overloaded due to an increased amount of information as well as the information presentation being too complex and inconclusive. The sub-category 'Unreliable/immature technology' includes statements about how it is a concern of pilots that technical systems do not function properly, leading to a loss of trust. The sub-category 'Ethical concerns' is comprised of ethical concerns of pilots to not be included in decisions involving lethal strike manoeuvres.

Both the concern regarding workload as well as the concern that pilots might not be sufficiently included in the design process of the NGF were topics found to be relevant throughout different interviews and were discussed in depth by the participants.

Table 2: Perceived risks of new technology in the NGF.

Category	Sub-category
Perceived risks of new technology in the NGF	Over-engineering
	Individual differences among pilots
	Workload
	Unreliable/immature technology
	Ethical concerns

The category 'Interaction with UAVs as part of future tactical and strategic mission execution' has a total of three sub-categories (see Table 3). The sub-category 'Perceived advantages of UAVs' includes perceived benefits of UAVs compared to standard manned formation flying. Discussed topics of this sub-category are improvements of the situational awareness (SA) of pilots, increased safety, decreased financial costs, and improved combat power. The sub-category 'Interaction with UAVs' includes interaction aspects in the context of UAV management. Here, relevant topics include interaction modalities, visualised representation of UAVs and their respective actions, and envisioned concepts of task (re-)allocation. The sub-category 'Limitations of UAVs' includes perceived disadvantages of UAVs. Discussed topics were shared responsibility, restricted reaction behaviour, cost-benefit ratio, and reliability.

Both the interaction topic, especially communication via speech, as well as the advantages of UAVs were topics of the participants' answers when asked about the collaboration with UAVs.

Table 3: Interaction with UAVs as part of future tactical and strategic mission execution.

Category	Sub-category
Interaction with UAVs as part of future tactical and strategic mission execution	Perceived advantages of UAVs
	Interaction with UAVs
	Limitations of UAVs

The category 'Requirements for adaptive automation functionality' has a total of five sub-categories (see Table 4). The sub-category 'Requirements for adaptive automation behaviour' includes requirements pilots have towards adaptive automation behaviour with topics like transparency, intelligence, override functions, and overall purpose of adaptive automation. The sub-category 'Trigger requirements' includes opinions of pilots in regard to HMI triggers. Here, pilots had similar opinions demanding adaption based on workload level, flight-phases, external environment factors, and physiological parameters. The sub-category 'Support concept' includes requirements regarding how pilots imagine support through adaptive automation and the process of task (re-)allocation. The sub-category 'Trust & Acceptance' includes requirements pilots have for the adaptive automation in order for them to trust and accept it. The sub-category 'Limitations' includes requirements of pilots based on limitations they expect the adaptive automation to have.

Table 4: Requirements for adaptive automation functionality.

Category	Sub-category
Requirements for adaptive automation functionality	Requirements for adaptive automation behaviour
	Trigger requirements
	Support concept
	Trust & Acceptance
	Limitations

Within this category, the topics of adaptive automation behaviour as well as the trigger requirements for when an adaption should take place were discussed often and in detail.

4 DISCUSSION

The focus of this study was to collect opinions of pilots regarding interfaces in, to them, familiar cockpits and regarding new interface aspects imagined to play a role in the NGF cockpit. Based on their subjective opinion, the aim of this study was to create initial requirements for the HMI within the NGF. To accomplish this, expert interviews were conducted as means of data collection. Results derived from the hybrid coding method state four categories, each with multiple sub-categories assigned. However, before diving into the discussion of each category, it is important to note that statements about specific aircraft and interfaces are abstracted for safety-critical reasons, such as to avoid pointing out flaws in specific military aircraft.

4.1 Opinions on HMIs

Within the category 'Opinions on HMIs/Information sources within the cockpit', statements about multimodal interaction elements and the way of information presentation appear to be most relevant, as aspects of these two topics were discussed in depth throughout the interviews.

Regarding multimodal controlling, pilots appear to prefer hard keys. Arguments in their favour include better haptic proportions, supporting pilots in differentiating buttons from each other as well as enabling pilots to operate them blindly. Interviewed pilots agreed upon the fact that hard keys provide better feedback when being pushed compared to using touch or soft key buttons. "I need feedback, that is why I like hard keys personally, if I only have a display, I firstly don't blindly find the button and secondly I do not know whether I actually pushed the button", said one pilot. However, touch is not unanimously disliked either. Especially faster and easier command possibilities are recognized here but it is made clear that pilots do have reservations about using touch in every situation. Touch in combination with high G-forces is seen as problematic, but also in combination with equipment like wearing gloves, the functionality of touch buttons is perceived as critical. In any way, whether touch or hard keys, feedback and distinguishability appear to be important requirements here. Additionally, speech commands and controlling via body movements like gestures or eye tracking were discussed. Here, opinions of interviewed pilots differ. While some see time-wise advantages of controlling technology like eye-tracking were recognized, concerns regarding unintentional inputs through unconscious movements or noise of the environment interfering with speech were found to be relevant, as well.

Continuing with the sub-category 'Information presentation', pilots appear to agree that important and often used information should be visually presented within the centre of the cockpit. Hereby it appears important to have a decluttered interface with intuitive menu layers and simple information presentation. Opinions differ on how information should be presented as some claim that abstract/symbolic presentations enhance the recognition whereas others argue that too much use of abbreviations can lead to confusion. Requirements for information presentation are therefore to present important information in the centre of attention and create decluttered and intuitively structured menus. The manner of presenting different information either through visual or auditive means should be further researched as no clear requirement could be formed here based on the opinions of pilots.

Less relevant sub-categories included the arrangement of control elements and general HMI requirements. Regarding the former, pilots agreed that an emphasis has to be on safety critical features like control elements being easy to reach and should not be concealed. "In single seater cockpits, the tendence is that control elements are build up in a U-shape around you. This is problematic if essential buttons which you often need to use are somewhere almost behind you", explains one pilot. Additionally, the wish for personalization of layouts was mentioned, but with the annotation that standardized set-ups should not be disregarded either. Moreover, a safety feature hindering pilots to involuntarily activate a safety critical button or lever appeared to be relevant. The sub-category 'General HMI requirements' entails demands regarding the general HMI set up. Here, pilots agree that the way in which information is presented as well as choosing which interaction modality to use should be basic, user friendly, and fit for purpose. Especially the 'KISS principle' (keep it simple & stupid) appeared to be relevant to pilots during the interviews.

4.2 Perceived Risks

Regarding the category 'Perceived risks', concerns regarding over-engineering and workload appear to be the most relevant for pilots.

The sub-category 'Over-engineering' included concerns of pilots to not be integrated enough in the design process. Here, pilots uniformly agreed that, if not included, the NGF will present information incorrectly, i.e. at the wrong place and at the wrong time, as well as include features which are too complex for the given environment. "So we overcomplicate some of the displays because they are not designed for pilots but for those great ideas", stated one pilot. Therefore, a requirement is to include the user throughout the whole design process, as multiple HFE standards state.

Within the sub-category 'Workload', statements of pilots which refer to the concern of being overloaded with visual and auditive information are listed. Almost all pilots agree that they fear the increased amount of information of the NGF being too much to process. Controversially, there are also statements of some pilots expressing the wish to have most information visible somewhere. Therefore, the requirement of not being overloaded with information has to be researched in more detail to establish how much information and which type of information should be made available to pilots in different situations.

Less relevant were the sub-categories 'Individual differences among pilots', 'Unreliable technology', and 'Ethical concerns'. In comparison to the concern that pilots will not be integrated within the design process, the comparatively lesser talked about concern was that only a specific type of pilots would be included. Thus, a further requirement is to have a sufficiently representative sample population of pilots. Uniformly expressed concerns within the unreliable technology sub-category are tied back to the expectation of pilots that equipment will not always function as intended and that, therefore, a requirement should be that a fail-safe mechanism has to be implemented. Lastly, ethical concerns are uniformly expressed with pilots stating that they have to be in- or, at least, on the loop when it comes to firing weapons.

4.3 Interaction with UAVs

Regarding the category 'Interaction with UAVs', the topic of interaction was discussed most detailed, followed by expected advantages of the introduction of UAVs and, lastly, expected limitations.

Within the sub-category 'Interaction with UAVs', the use of auditive communication channels (i.e. voice) was discussed in great detail. Opinions of pilots are split regarding this topic, with advocates stating that voice is the known routine and that it does not require the visual attention of the pilots being directed inwards, e.g. at a screen. Adversaries state that the use of voice is too unreliable as command input and also not compatible with situations in which the pilot is subjected to high G-forces. Also, the communication from UAV to pilot appeared relevant, with pilots stating that it would probably be best if it was situation dependent, but feedback would be necessary in any case. Therefore, no clear requirement can be formed here as opinions were almost evenly split indicating the need to research this question further.

Within the sub-category ‘Perceived advantages’, it becomes apparent that pilots indeed see the inclusions of UAVs as a positive development in the field of military aviation as this could improve combat power, lower the risk for pilots by reducing the need for humans to enter hazardous territory, and gather more information, thereby increasing SA.

Limitations, however, were also part of some discussions. Here, pilots were mainly concerned with the management of UAVs unnecessarily increasing workload. One pilot stated:” We must avoid creating more task load for the single remaining pilot up there. The crew must make decisions and it cannot be that the rest of the time, the pilot is busy making micro adjustments”. Thus, the avoidance of micro-management can be seen as a requirement of collaborating with UAVs. On the other hand, interviewed pilots insisted that critical decisions should remain in their responsibility, as the creativity in forming decisions is seen still as major advantage humans have over machines.

Explicit requirements for this category are hard to establish as opinions of pilots differ a lot, but what can be derived is that pilots do not want to control every little movement of the UAVs but instead take on more of a management role.

4.4 Requirements for Adaptive Automation

Within the category ‘Requirements for adaptive automation functionality’, requirements for adaptive automation behaviour were discussed in most detail during the interviews. Here, especially transparency was a requirement discussed in detail. Pilots agreed that the actions of the adaptive automation have to be transparent in order to trust it and not destroy their SA. One pilot explained: “Theoretically, if the aircraft told me that it changed from system state A to B, that would be great, but if it wildly switches around and I can not trust it, that would be bad”. Other aspects of the transparency that were discussed were predictability and reasons behind the adaption. Another requirement discussed within this sub-category is the ability of an override. Pilots unanimously agreed that this is a function that has to be present. Additionally, it was unanimously agreed upon that the adaptive automation should not replace the pilots but support them. In other words, automation should not take away the control pilots have, but take on more of an assistance function supporting the pilot. To clarify, this does not imply that the pilot cannot surrender tasks to the automation. That is a prospective function very much appreciated by pilots. Instead, the requirement deduced here is that if the system does not keep the pilots in the loop, it should at least support them in staying on the loop. Furthermore, the topic of intelligent adaption appeared to be relevant. For example, a rejection strategy for multiple denied actions by the pilot was mentioned.

The next sub-category (‘Trigger requirements’) in line for being extensively discussed included opinions of pilots in regard to which triggers to use for the adaption. In relation to this, handling of emergency situations was discussed in detail. The handling should either include passively supporting the pilot through the correct depiction of instructions about what to do or actively intervening. Additionally, pilots listed workload, flight phases, and external factors (e.g. brightness of sun) as acceptable triggers for adaption, whereas physiological parameters were seen as critical by almost every pilot interviewed. “It might be even more dangerous to monitor the pilot and depending on this, change the HMI because that will destroy his SA in a second”, elaborated one pilot. Therefore, requirements for the sub-category ‘Trigger requirements’ include adding emergency situations, external environmental factors, workload, and flight phases as trigger for adaption while excluding physiological parameters.

A less detailed discussed sub-category was ‘Trust & Acceptance’. Here, pilots either had the viewpoint that reliability of a system function produces trust or that a declining advection to the adaption (i.e. auditive warnings first, then adaption proposals at second, reduction over time to warning only) would be helpful. However, others also stated that, since their life is on the line, they are forced to trust the system, therefore trust does not matter. The most basic requirement unanimously agreed upon here was that the system has to function as intended as, apparently, the malfunction of systems was an often occurring issue in past fighter models. Due to the diversity in answers, no further requirement can be formed here, therefore, further research into this topic is recommended.

The last sub-category ‘Limitations’ included drawbacks perceived by pilots towards adaptive automation. Here, pilots appear to agree that adaptive automation should not take away their responsibility of making decisions, especially when being confronted with new or unknown situations. Also, it was discussed that the intelligence of technology, i.e. artificial intelligence, is (as of now) still below the intelligence of humans when being confronted with unknown situations. Therefore, the responsibility to decide what to do should still be left to the pilot.

4.5 Conclusion

In conclusion, the following requirements were established out of the expert interviews: The first category produced the requirements of feedback and distinguishability for the different input elements, centred information depiction and decluttered/intuitive menu build ups, and simple interaction modalities which are easy to reach and not obstructed. The second category produced the requirements of including (representative) pilots all throughout the design process, not overloading the pilot with information, and including a fail-safe mechanism in case of technological malfunction. The third category produced the requirements of not having to micro-manage each single UAV, as these should support them instead of adding to their task load. The fourth category produced the following requirements: Feedback of automated behaviour (i.e. pilot on the loop), an override function, transparent adaptive behaviour, and the avoidance of taking away the authority for making decisions and taking responsibility from the pilots.

This study did not include a large sample size (N=11), which is acceptable for its explorative qualitative nature. Still, it would be interesting to conduct quantitatively structured research with a larger sample size using actual prototype concepts, to further study the requirements deduced here. In any case, the inclusion of representative stakeholders as well as the integration of HFE expertise is seen as essential for the success of the FCAS program.

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APPENDIX

Appendix A

Semi-structured interview questions:

1. Which role/tasks did you have in the aircraft?
2. Which aircraft models did you fly?
3. What are your opinions about single interfaces and/or sources of information in cockpits of aircraft you are familiar with:
    a. Particularly good interfaces?
    b. Particularly bad interfaces?
4. What risks do you see in regard to the cockpit of the NGF:
    a. In regard to adaptive automation?
    b. In regard to the collaboration with UAVs?
    c. In regard to new interaction technologies?
5. Is there anything else you would like to see in regard to interfaces of the NGF?

Appendix B

Table 5: Self-developed coding guideline after Mayring.

Category	Definition	Example	Coding Rule
Opinions on HMIs/information sources within the cockpit	All text passages which include a subjective experience about HMIs of current or future cockpits allowing two-way communication	"In single seater cockpits, the tendence is that control elements are build up in a U-shape around you. This is problematic if essential buttons which you often need to use are somewhere almost behind you"	Interview passage must express an experience of a past, current, or (possible) future HMI which either hinders or reinforces the performance of pilots
Perceived risks of new technologies in the NGF	All text passages which include a perceived risk or concern of pilots with respect to technologies/capabilities of the NGF	"To be overloaded with functions and information I cannot process is my number one priority of what must not happen"	Interview passage must express a concern in relation to the capabilities of future technology of the NGF and/or its consequences for the human
Interaction with UAVs	All text passages which include an subjective opinion about collaborating with UAVs	"We must avoid creating more task load for the single remaining pilot up there. The crew must make decisions and it cannot be that the rest of the time, the pilot is busy making micro adjustments"	Interview passage must express an opinion about UAV-related technology and/or an envisioned way of collaboration/interaction between manned and unmanned platforms
Requirements for adaptive automation functionality	All text passages which include a requirement of pilots for the functional behaviour of adaptive automation	"What has changed is the level of automation in the flight controls which I read directly as assistance. And that assistance does change depending what you are doing which leads to other problems that ,often, pilots do not know what the aircraft is doing"	Interview passage must express a wish/requirement for the functional way of working of adaptive automation in a collaborative context