# Applied Cognitive Ergonomics Design Principles for Fighter Aircraft

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**Abstract.** The objective of the reported work was to study the use and applicability of applied cognitive ergonomics design principles for fighter aircraft, with examples from the modern Swedish swing-role aircraft Gripen. Methods used were a literature review of relevant design principles together with an analysis of their applicability to the fighter aircraft domain as well as interviews of developers and scrutinized system documentation of ongoing fighter aircraft development at Saab. As a result of those activities, we can here present a brief description of cognitive ergonomics design principles applied in the Gripen fighter aircraft, and the development process for human-machine interaction for fighter aircraft. Finally, considerations for the design process for fighter aircraft are discussed in the context of that description.

**Keywords:** Fighter Aircraft, Design Principles, Cognitive Ergonomics, Human-Machine Interaction.

## 1 Introduction

For fighter aircraft it is very important to achieve good human system integration. It is important to regard human factors in, for instance, display design, for the fighter pilot and the aircraft to perform optimal together. This is important for safety reasons, since flying an aircraft is in itself an activity that is potentially dangerous and even more so in a hostile environment. Also, it is important to regard human factors for reasons of performance which are central for fighter aircraft. The pilot interaction is often essential and is sometimes a bottleneck in the decision making process involving decision support systems and other automation with human-in-the-loop decisions under high demands, such as high mental workload and situations requiring high situational awareness.

The cockpit design, including display design and interaction design has evolved through a process including various amounts of elements such as, design tradition, user involvement, structured design processes, human factors knowledge and more. As part of a local initiative for efficient development of fighter aircraft, the reported study was performed, focusing on efficient development of fighter aircraft interaction

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design, including methods and examples of usability design principles in the modern Swedish swing-role aircraft Gripen [1].

The objective of the reported work was to study the use and applicability of applied cognitive ergonomics design principles for fighter aircraft, with examples from the Gripen aircraft. By the use of methods for literature review, interviews, and analysis, descriptions are presented of cognitive ergonomics design principles applied in the Gripen fighter aircraft, and the development process for human-machine interaction (HMI) for fighter aircraft, below.

This work is not only relevant for the domain of fighter aircraft development, but also for other application areas where design principles within cognitive ergonomics are to be adopted into applications where successful human system interaction is central. However, the fighter domain has specific constraints to be regarded when studying the applicability of cognitive ergonomics design principles.

## 2 Fighter Domain Constraints

Even though the demands of the fighter aircraft domain are very special, just as many other domains are special in their own sense, general design principles were found to be useful for describing the pilot-aircraft interaction in this case, which supports the idea of general design principles, although it is important to be aware of the specific requirements of the domain. By designing for what is special about a fighter pilot, a fighter aircraft and the flight environment relevant design concepts can be formed from design criteria [2].

Fighter pilots are a homogeneous group, especially compared to users of consumer products, e.g. mobile phones or cars. The group contains neither old users, nor very young, and they are selected thoroughly with regards to, for example, mental capabilities and anthropometrical characteristics. They have all successfully carried out the same demanding pilot training and thereby acquiring the skills and procedures needed. While it is, of course, easier to design for a homogenous user group it is important to stress the fact that the demanding context for a fighter pilot still provides extreme challenges from a design point of view.

There are high demands on a fighter pilot regarding rapid decision-making. Decisions must be made under extreme time pressure in a hyper-dynamic setting in a hostile environment, typical for naturalistic decision making [3]. There are several aspects that are important for a fighter aircraft domain, and many of them could be said to be extreme. Some examples are:

- High G-loads
- High mental workload
- Sudden and drastic light conditions and high visual demands
- Demands on rapid decision-making in a battle of life and death

In scenarios with high G-loads the pilot's interaction possibilities are degraded which needs to be considered during the design process.

# 3 Method

Methods used were a literature review of relevant design principles together with an analysis of their applicability to the fighter aircraft domain as well as interviews of developers and scrutinized system documentation of ongoing fighter aircraft development at Saab. A literature review on usability design principles and interviews of system developers at Saab [1] were complemented with further analysis to find suitable descriptions of the development process for HMI for fighter aircraft. Below the methods used are described, and the outcome is presented in following chapters.

## 3.1 Interviews

Interviews were initially performed with four very senior developers of HMI for fighter aircraft at Saab. They were all men between 42 to 65 years of age, and each had between 17 to 40 years of experience of the domain. First, all respondents were interviewed through topic focused, semi-structured interviews at one or two occasions each. To ensure that the respondents were to address the same topics, themes for the interview sessions had been prepared in advance. The notes from each interview were fused with the other notes and were validated and further elaborated in a group interview/workshop with all but one of the respondents present. These interviews were specifically concerned with design principles, and were followed by unstructured interviews to complement the analysis of the development process.

## 3.2 Literature Review

A review of the research field of relevant design principles was conducted. Also, system documentation of ongoing fighter aircraft development at Saab was scrutinized.

## 3.3 Analysis of Design Principles and Development Process

Based on the interviews and the literature review an analysis of design principles was performed. Design principles from literature were systematically mapped towards the outcome of the interviews and described in examples of the type presented below. Similarly, but less structured, an analysis of the development process were performed based on the outcome of unstructured interviews.

# 4 Cognitive Ergonomics Design Principles Applied in the Gripen Aircraft

The examples below are in part based on analysis of usability design principles for the Gripen aircraft [1], but are also selected to be suitable examples for a reader that does not necessarily have experiences from the domain. One category of design guidelines found in the literature and in the interviews had to do with *Consistency* (Fig. 1, Fig. 2, Fig. 3, and Fig. 4 show examples). Examples of these guidelines were: what look alike, should act alike [4], the same actions should lead to the same result [5], similar situations should be handled similarly [6], be consistent in automation [7], and be consistent in formatting, terminology, positioning, attention grabbers, etc. [8].

Another category is related to *Support of user mental models* (Fig. 2, Fig. 3, and Fig. 8 show examples). Examples of these guidelines were: use clearly defined conceptual models in display design [9], mirror the user's mental model - not the designer's, mimic well known concept and such that is previously learnt, talk the user's language, give feedback, avoid irrelevant information, develop for both experts and novices but protect the novices from complexion [5], all the information needed for a task should be available when performing the task [10], use system visibility, and what moves on the screen should follow the user's mental model of what actually moves [9].

A third category had to do with *Keep it simple* (Fig. 2, Fig. 5, Fig. 6, and Fig. 7 show examples). Examples of these guidelines were: eliminate what doesn't add to efficient use [4, 5], information used sometimes, shouldn't be displayed always [11], use visual hierarchy [4, 5], use default settings, more common tasks should be made easier [5], display data in a directly usable format for the user [12], limit the number of separation lines [13], simplify symbols as far as possible while keeping the understanding [14], group primary information on one display [15], minimize user options [5], and group information that is integrated mentally together [9].

A fourth category is related to Use of color (Fig. 8 shows an example). Examples of these guidelines were: design for monochrome, add color only as redundant information [4, 5, 6, 15, 16], limit number of colors to about 5±2 [4, 6, 14, 15, 16], avoid overuse of color (noise) cf. [17], follow user expectations and domain color usage [5, 6] use conventional colors for danger/warning/normal – red/yellow/green [17], be consistent in color usage throughout the system [4, 16], for bright background use low-intensity colors such as off-white, for dark background use cool colors like black or blue, foreground and background should have good contrast [5], use sharp colors to grab attention [16].

More categories like "Multimodality/redundancy" were also found in literature and application but will not be described here.

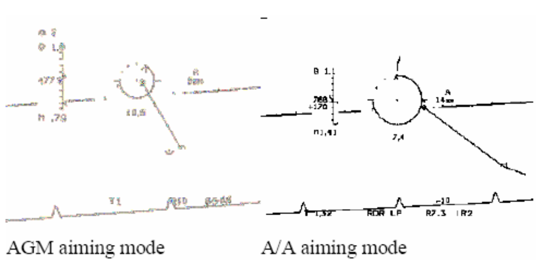


**Fig. 1.** HUD Aiming modes (consistency)

With the introduction of Gripen as a multirole fighter in the Swedish air force the same pilot was supposed to perform several types of missions previously done by specialized pilots. In order to ease the training the HMI for similar tasks were designed to be as similar as possible rather than being optimized for each task separately. Examples of this are the gun and missile aiming modes, where similar display and controls are used regardless of target types like aircrafts, ships, buildings or land vehicles.

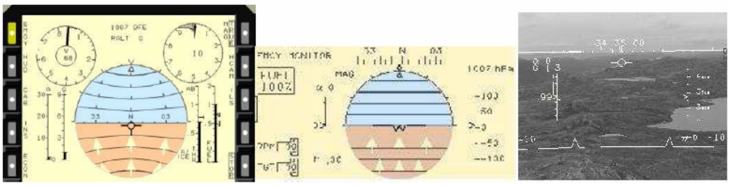

**Fig. 2.** Basic T (Consistency, Support of user mental models, Keep it simple)

Consistency in design because of pilot training is nothing new. During World War II and in the early days of the cold war new aircraft types were being introduced at a remarkable rate. The pilots then had to convert from one aircraft type to another and then relearn the user interface. During stress humans have a tendency to revert to the basics they learnt and when the user interface differed accidents could happen. In order to mitigate this, the “Basic-T” concept was created as a design guideline for how the primary flight data instruments should be located relative each other in the cockpit. Even modern day electronic flight instruments adher to the “Basic-T” concept.

The mental model for attitude display in Gripen is to think of the aircraft as positioned inside a giant fixed sphere where each ten degrees of pitch and heading is indicated. It is also an example of the “inside out” conceptual model used throughout the Gripen displays.

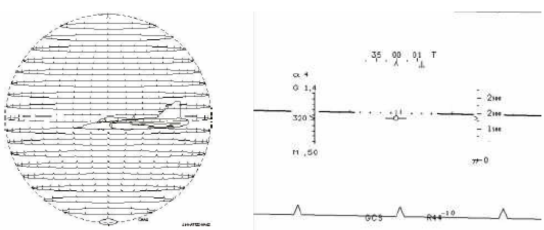

**Fig. 3a.** Attitude display (Consistency, Support of user mental models)

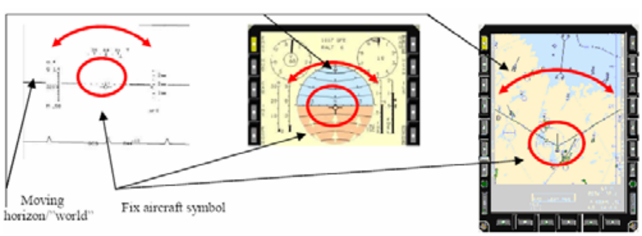


**Fig. 3b.** Attitude display (Consistency, Support of user mental models)

The design guideline “what moves on the screen should follow the user’s mental model of what actually moves” is one of the reasons behind the “inside out” conceptual model and as can be seen affects not only the Head Up Display but map displays and Attitude Direction Indicators.

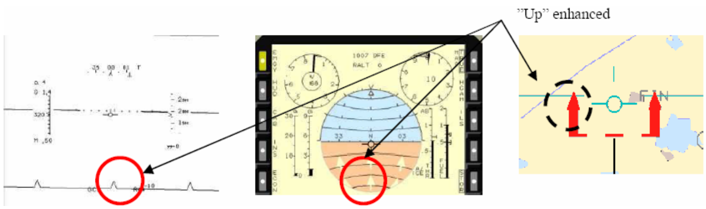


**Fig. 3c.** Attitude display (Consistency, Support of user mental models)

The way “up” is enhanced for potentially dangerous attitudes is both consistent and complies with the mental model of attitude.

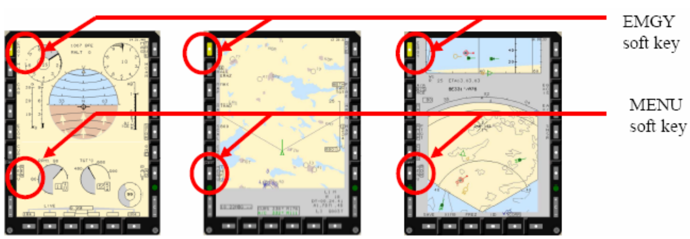


**Fig. 4.** Soft key positioning (Consistency)

Standard soft keys are located at the same position on all displays and have same or similar results when activated.

**Fig. 5.** Hiding irrelevant tactical data (Keep it simple)

When ground collision warning is given the pilot’s focus should be on saving the aircraft so all tactical data is turned off on the more information intense displays.

**Fig. 6.** Emergency instruments (Keep it simple)

In Gripen C/D there are no longer any dedicated standby instrument, instead every display can act as an emergency flight data display directly connected to the sensors.

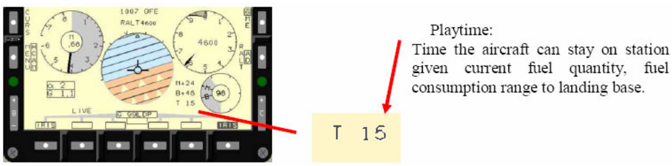


**Fig. 7.** Playtime (keep it simple)

An example of displaying data in a directly usable format for the user is the display of "playtime" rather than displaying fuel quantity and fuel consumption rate that was the norm in older aircraft.

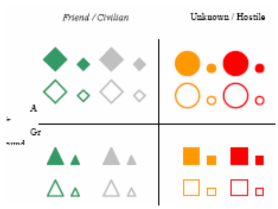


**Fig. 8.** Target symbols (Color, Support of user mental models)

The target symbols are designed to work even when color is hard to see when display lighting is turned low at night to preserve the pilot's night vision. Color is however used to enhance the target symbols, making them easier to group. A target symbol can represent data from many different sensors but these are fused into a single display symbol to support the pilot's mental model of "one object".

## 5 Development Process for Human-Machine Interaction for Fighter Aircraft

Positive qualities of formalization of applied cognitive ergonomics design principles were found for the integration of human factors considerations into the development process of fighter aircraft. However, the development process was found to be only partially influenced by applied cognitive design principles and we could not fully describe the impact of other influences of the design, in the design process at hand. However, the use of style guides were found to be used as a means of implementing design principles into the design process.

The design process for HMI is a central part of the development process for fighter aircraft. The design process itself can be designed, through both technological design as well as institutional design [18], since in parallel to an architect that designs a building, an organization could also be designed [19]. It is important to regard user needs when the design process is formed, either by direct involvement by users or indirectly by for instance descriptions of user behavior or general design principles. Often a designer regards the user as subsystem of the total system and is perhaps modeled through design principles or scenario elements, depending on the types of meetings in the applied design process [20].

The development process at Saab for HMI has for a long time been concerned with simulator-based design in the development of Swedish fighter aircraft [21]. Saab has developed a process with emphasis on rapid prototyping and found it to be successful. When reassessing the characteristics of the current design process simulator-based design was still found to be central. Early and frequent user involvement in an iterative design process are still heavily influencing the design, perhaps more than formal descriptions of cognitive ergonomics design principles. Singer [22] has presented how part-task simulation in an early part of the design process was useful for designing commercial aircraft cockpit systems. In the development process for HMI for fighter aircraft there is a special role for a style guide to apply cognitive ergonomics design principles.

Since HMI design work is performed in close connection to various functions in cockpit there is a risk that the design will diverge between different design teams which leads to a total design that is inconsistent. One tool used to mitigate that risk is a HMI style guide. The HMI style guide is used to document and distribute general design decisions and it contains the design philosophies and design rules that are the foundation of work within the HMI design in the cockpit. Examples regarding the design philosophies are support of mental models, redundancies and manageable work load. The design rules are to be followed when working with the development of functions that involves interaction between user, usually the pilot, and the system. The content of the style guide should be based on relevant ISO and Military standards, public HMI guidelines and own experiences from development of aviation systems. Updates are conducted regularly based on experience made in ongoing development and changes or supplements in standards and international HMI research.

One risk when inserting a style guide is that it will be seen as a guarantee for a usable system and that its existence makes other essential design activities unnecessary. It is important to stress the fact that the style guide shall be regarded, and managed, as a support to the HMI-developers and not as a template of making a useful system and, accordingly, does not lessen the need for a user centered design process with its associated activities.

## 6 Discussion and Conclusions

This study has shown, on the level of provided examples, that cognitive ergonomics design principles are applied for fighter aircraft. Further, the applicability of cognitive ergonomics design principles in the design process was studied. It was found that cognitive ergonomics design principles influence the design, directly or by the use of descriptions such as style guides. However, it was also found that, in the studied development context, the design principles were processed and formed in the design process, so that a specific design principle was unlikely to be uncritically implemented, automatically, but rather by a compromise with other input to the design process.

Even though the focus of this study was cognitive ergonomics design principles it may be interesting to reflect on what this complementary input to the design process is. For instance, standards influence the design, design tradition influence the design, as well as contextual demands and technical or economical constraints on the design process. Also, there may be conflicts between different design principles for a specific design decision. For instance, the principle of consistency often is in conflict with other design principles describing their "local good" (optimizing for that specific design principle).

An example of when the principle of consistency could be in conflict with design tradition is that most often imperial units are used in aircraft and metrical units are often used by ground based army units. However, when they are cooperating, for instance in a close air support mission, the designer of the pilot interface has to handle that.

Contextual constraints for the fighter domain, as described earlier, are central for the design of pilot interfaces. An example of a conflict between the contextual constraints and a design principle could be when designing for access of two types of sensors. If one sensor has to have high access, since it, for instance, is critical for dogfight it may not be designed to be handled in the same way as another senor with low access demands, used for, for instance reconnaissance. Since standards partly are based on design principles you may think that there would never be a conflict between what is stated in a standard and a design principle. However, this is not always the case. For instance, if a civil standard for radio navigation is using a lot of colors it is hard to both follow that standard and at the same time optimize the use of colors for the rest of the interface, and at the same time keep consistency throughout the design.

The perhaps most common conflict is the one between a design principle and technical and economical constraints. Especially technical limitations are often hard to change even if they are in contrast with a design principle. For instance, at the time when no color displays had been developed and tested for fighter aircraft principles for use of color could be in conflict with those constraints.

However, in this study not only conflicts were found between fighter domain constraints and cognitive design principles applied in the Gripen aircraft, in the development process for HMI for fighter aircraft. Positive qualities of formalization of applied cognitive ergonomics design principles were found for the integration of human factors considerations into the development process of fighter aircraft. The performed study has influenced the HMI design process at Saab. For instance, the use of style guides has been improved, as one tool among others to link general design principles to the demands of a specific design process.

To conclude, this work has studied the relevance of applied cognitive ergonomics design principles for fighter aircraft. Design principles are relevant for human factors considerations in development, although design principles are only one of many sources of information for a designer. For instance, the domain specific design tradition regards what is unique for the domain, so the general design principles has to be adjusted to what is unique for the domain to be competitive in domain specific human factors evaluations, such as human-in-the-loop simulations.

Future research is needed to develop methods and approaches for enhanced use of applied cognitive ergonomics design principles for fighter aircraft. Recently a national research project has been started supported by The Swedish Governmental Agency for Innovation Systems (VINNOVA) through the National Aviation Engineering Research Program focusing on innovative and effective system development for military aircraft studying how qualitative and quantitative assessment of pilot decisions can be applied through formal descriptions of design in a so called "Brainbudget", such as time to decision, amount of mental workload etc. Future research could also be focused on comparisons between various development contexts, such as other domains, to better understand how the findings from this work compares to related work with other constraints.

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