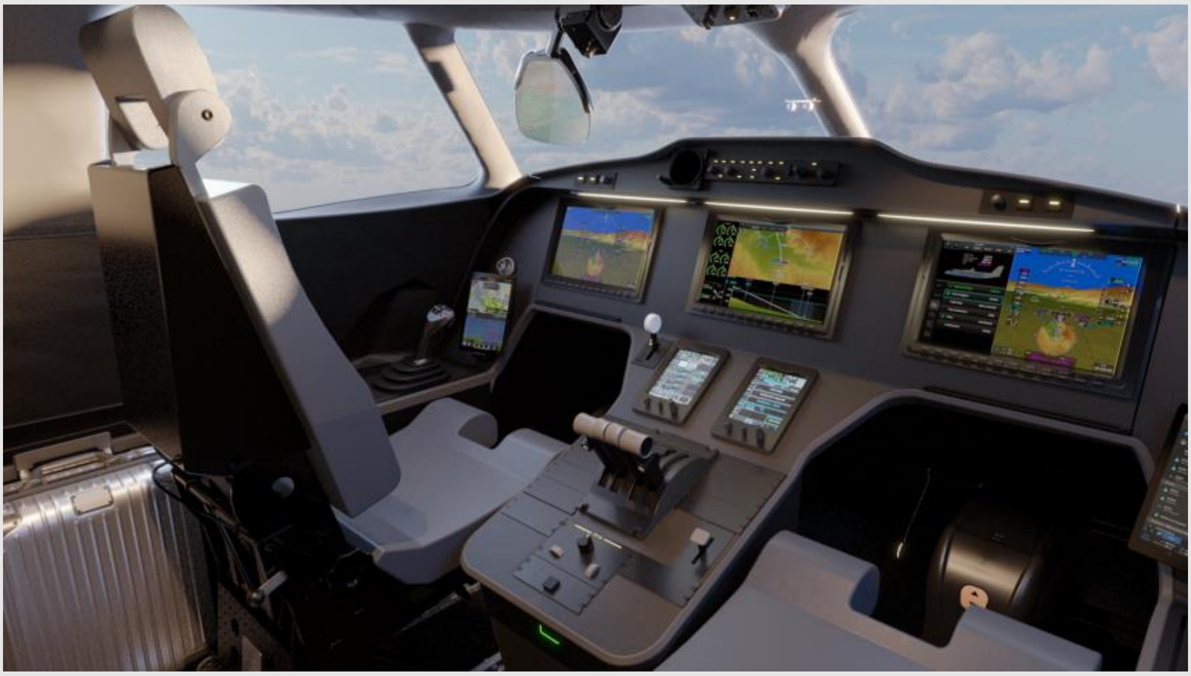

Human Factors Design Recommendation Optimisation

A process development for human-machine interface of the battery status on flight decks for electric regional aircrafts

M.Sc. Thesis in Product Development and Sustainable Energy Systems

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Cover: The image shows an old flight deck rendering, which serves as a previous illustration example of the flight deck design by the company.

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Abstract

The objective of this research is to investigate the integration of human factors in the development of a battery human-machine interface (HMI) for electric regional aircrafts. The study aims at examining how the integration of human factors can be improved in the development of novel features in the flight deck. Secondly, the study aims at analysing how the energy density of batteries compared to fuel affects the design considerations of the battery HMI for electric regional aircrafts. Lastly, the study is evaluating if low-fidelity prototyping is an effective way of validating the effectiveness of the process.

The methodology used in this study is based on an interactive design process combined with a product development process. The results were an implementation of a clear and structured process, which involves relevant stakeholders at each stage of development and utilises visual aids for better understanding, leads to effective collaboration and streamlined development. The final process design uses an agile approach with steps, iterative feedback-loops with each relevant department's responsibilities clearly stated. Furthermore, the design of the battery HMI for electric regional aircrafts must take into account the lower energy density of batteries compared to fuel, which places a greater strain on pilots and the plane's ability to estimate and supervise energy usage. Lastly, low-fidelity prototyping is an effective way of validating the process, as it highlights both the advantages and disadvantages of the early stages in the approach and identifies areas for improvement in a fast paced way.

Keywords: Human factors, Human-machine interface, Process development, Battery management, Aviation, Electric regional aircraft, Process optimisation.

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Hedvig A Sally Ivarsson

Hedvig Arosenius Sally Ivarsson
Gothenburg, July 2023

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List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

AMC	Acceptable Means of Compliance
CASFW	Collision Avoidance System-Function Window
EASA	European union Aviation Safety Agency
FMS	Flight Management System
HFE	Human Factors Engineering
HFI	Human Factors Integration
HMI	Human Machine Interface
MFW	Multi-Function Window
SIW	System Information Window
SOC	State of Charge
SOF	State of Function
SOH	State of Health

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Contents

List of Figures

List of Tables

1

Introduction

The aviation sector is one of the main contributors to global-energy related CO_2, and is constantly growing [1]. With advancements in battery and aerodynamic technology, regional air travel is becoming greener and more sustainable thanks to electric regional aircrafts [2]. In addition to supporting the environment, electric regional aircrafts might have the potential to revolutionise the aviation sector and produce more effective and affordable transportation options.

There are still several obstacles in the way of the widespread use of electric aircraft. One of the primary operating challenges for these aircrafts is the control of the onboard energy systems, particularly the battery system [3]. To make them operate safely, effectively, correct, and dependable, battery levels must be shown in the flight deck. There is an opportunity to improve how human factors design recommendations are made and integrated into the final flight deck design. Human factors define a flight deck philosophy as well as a considerable number of design recommendations for the flight deck along with energy management control, which is a novel technology to be integrated into the first flight deck of this scale-up company. These design proposals are converted into engineering requirements, which should then be represented in the flight deck's final design.

The structure for making design recommendations for the flight deck today is through an approval meeting. This group discusses design issues that the different stakeholders within the company submit by filling out a form describing the issue. Today, the information filled in the forms may vary across the engineering teams, making it difficult to interpret and prioritise issues. For novel, integrated and complex systems to be managed in this process more efficiently, there is a need for streamlining of the input to the approval meeting. This is a central part of the current Human-Machine Interface (HMI) design process.

1.1 Background

This thesis is in collaboration with a Swedish scale-up company developing electric regional aircrafts. With the new type of propulsion, the one thing yet not investigated for this company in the flight deck design is the display of the batteries' energy level and what this means within concept of operations. This is due to the amount of energy that is accessible from a battery varies and is dependent on a variety of factors such as load, temperature, frequency of charging cycles, pilot handling and are contributing to the available energy. This is in contrast to a regular fuel tank where the amount of energy is a fixed amount and varies very little. As a result, it is extremely challenging to anticipate how much energy a battery will provide to give as much range as possible. From a human factors point of view, the flight crew should be given the ability to quickly and easily cross-check the system predictions by using rule-of-thumb energy calculations in conjunction with actual energy consumption monitoring. This is done to reduce the risk of an incorrect energy calculation caused by a flight crew error when inserting data in the flight planning tool. Therefore, there is a need to explore the possibilities with this and define a methodology as well as their own design philosophy that satisfies stakeholder needs while taking human aspects and energy management into account.

1.2 Aim and research questions

The aim of this study is to streamline the process up until the approval meeting for optimising the way human factors is incorporated in the development of the battery HMI. To fulfill the aim, the following research questions will be answered:

- How can the integration of human factors be improved in the development of novel features in the flight deck?
- How does the energy density of batteries compared to fuel affect the design considerations of the battery HMI for electric regional aircrafts?
- Is low-fidelity prototyping an effective way of validating the effectiveness of the process?

1.3 Delimitations

- Limited time frame
- The project is limited to the process of designing the flight deck's battery HMI and how human factors interacts with engineering systems and the concept of energy management.
- No design recommendations for aircraft batteries will be made.
- The project is limited to the company and their flight deck.
- Recommendations may not address the approval meeting content, i.e., only the streamline up until these meetings will be addressed.
- The content of the design process must follow the regulations stated by EASA in their CS-25 document [4].

2

Theoretical basis

This chapter provides a theoretical framework that underpins the relevant background of the design process of a flight deck. This includes the methods used today, importance of HMI, human factors integration (HFI), human factors design standards, guidelines, and best practice as well as the battery propulsion system. Additionally, different regulations regarding the aviation industry will be presented, such as safety, certifications, and frameworks from EASA.

2.1 Human factors within aviation

The frequency of incidents and accidents within aviation has been decreased thanks to international safety regulations [5]. Human factors and HMI play a significant role in incidents and accidents involving aircrafts [6]. In a world that is continuously evolving, aviation operations must remain flexible to effectively address new problems and utilize lessons gained to bolster the sector's accident prevention measures. Continuous improvement of human performance in operational settings is essential for both offline safety analysis and real-time operations [6]. The integration of all risk management components into a cohesive unit can be achieved through the implementation of an universal framework known as human factors.

2.1.1 Human factors design principles

Electric regional aircrafts require a complex array of systems and components to operate. To ensure that these systems are operated safely and effectively, it is important to design and develop effective HMIs and to integrate human factors considerations throughout design and development process.

An effective HMI is essential for ensuring that the pilot or operator can operate the aircrafts safely and effectively, even in complex or high-pressure situations. The HMI should be designed to be intuitive and easy to use, providing the information and controls that the pilot or operator needs in a clear and concise manner to reduce cognitive workload.

Human factors integration is the process of integrating human factors considerations throughout the design and development process. This includes the consideration of the physical, cognitive, and social factors that affect human performance, such as vision, attention, workload, and communication [7]. By integrating human factors considerations into the design process, it is easier to create systems that are safe, effective, and efficient for human operators.

In the context of electric regional aircrafts, HFI could be essential for ensuring that the complex array of systems and components work together effectively, while also considering the needs and limitations of the human operators. This includes the design and integration of systems such as the battery level display, as well as the overall design of the aircraft, including flight deck layout and the positioning of controls and displays.

2.2 Design regulations and standards

Within aviation, there are a large set of design regulations and standards that needs to be fulfilled for an aircraft to be approved. In this section, theory on the guidelines and regulations regarding existing certification will be presented and explained.

2.2.1 Aircraft type certification

Air travel is one of the safest means of transportation statistically, this is thanks to the many rules and high safety focus of the industry [8]. These rules and standards are a result of many years of development. These both help standardise the industry and to ensure a safe air travel for everyone, but it also makes the development process more complex for the manufacturers. Today, every aircraft needs to be certified to fly. The certification determines everything from development process and the organisation to human factors and performance [9].

The aircraft affected in this thesis is the company's developing electric regional aircraft. The size and calibre of this plane makes it fall under the certification of CS-25, large aircrafts. Therefore, the certification process is much more extensive than for smaller aircrafts [9].

There are multiple regulatory authorities: the aircraft will be certified under EASA, European Union Aviation Safety Agency. EASA has the mission to promote the highest safety standard in commercial flight on an European level [10]. Therefore, also partaking in rule implementation, knowledge sharing and support, and cooperation with other organisations. The responsibility of EASA is wide and contains more than just regulatory work on the aircrafts, for example, it also contains the education and training of pilots [9].

All aircraft models must obtain a type certificate that proves that the aircraft is airworthy [11]. This is an important step in aircraft manufacturing, and it consists of four steps: Technical Familiarisation and Certification Basis, Establishment of the Certification Program, Compliance demonstration, technical closure and issue of approval. The third step, compliance demonstration, is done through deciding on what is called means of compliance and these can be everything from demonstrating that the feature is identical to an already certified feature in use, to calculations and motivations. Sometimes a combination of different means of compliance are needed to pass certification [11].

EASAs guidelines affects the process as well. This means that thorough documentation is needed to trace back decisions made. EASA provides guidelines on how all of the certification bases should be worked with, and they have a flowchart that visualises the connection between multiple steps in the process. Within this process of acquiring the desired certification, EASA demands an evaluation of novelty, complexity and integration. A high degree of any of these properties would lead to a more rigorous process [12].

2.2.2 Safety

Accidents within the aviation industry can often be attributed to human errors within safety [13]. While there are many safety protocols in place to prevent accidents from happening, human error is still a common contributor to incidents and accidents. Some common examples of human error include miscommunication, incorrect procedural steps, lack of attention, and inadequate training [14].

To reduce risk, one of the safety models used is the Swiss Cheese Model which is based on a known framework used in safety and risk management to help identify and mitigate potential hazards and risks [15]. It is based on the idea that multiple layers of defence designed to prevent multiple errors that may add up and cause an accident. Each layer is represented as slices of cheese, with holes representing potential flaws or weaknesses in the system [15]. If all the layers are aligned, the holes are covered by the layers underneath and above, preventing errors from occurring. However, sometimes the holes might be aligned, and a potential hazard can pass through, leading to an accident or error [15].

To be able to ensure an acceptable low risk, risk assessments are made to evaluate the severity and the likelihood of an incident. By architectural structure, the absence of single-point failure is ensured.

2.3 Batteries

The batteries are crucial and critical components in developing electric regional aircrafts. Since this study explores a battery HMI through low-fidelity prototyping, relevant theory regarding this will be presented here for understanding the performance.

Batteries provide the energy needed to power the propulsion system as well as other necessary features and electrical systems onboard. The performance of a battery is measured by its energy density, cycle life and charge and discharge rate [16]. Energy density is the amount of energy that can be stored per unit of weight or volume. Cycle life refers to the number of charge and discharge cycles that a specific battery can undergo before the capacity degrades. Charge and discharge rate refers to the speed at which it can be charged and discharged without damaging its cells [17].

Throughout this thesis, three important battery parameters will frequently be referred to: state of health (SOH), state of charge (SOC), and state of function (SOF). The SOH of a battery refers to its overall condition, as determined by its cycle life. A battery's cycle life is closely linked to its SOH and SOC, since it affects its degradation rate. Importantly, a given percentage of SOC may not correspond to the same amount of energy stored in the battery at different stages of its life. Finally, the SOF represents the battery's trustworthiness in terms of fulfilling its intended function for the remaining flight.

2.3.1 Energy calculations with FMS

Pilots calculate the approximate fuel required for a flight using the Flight Management System (FMS), which is a computerised system that automates many aspects of flight planning and execution [18]. The FMS considers factors such as the distance of the flight, the weight of the aircraft, the prevailing winds, and the expected speed and altitude of the aircraft. Based on this information, the FMS will generate a predicted fuel consumption for the flight [18].

Pilots can monitor the fuel consumption using the FMS display and can adjust the flight plan if necessary to ensure that the aircraft has enough fuel to complete the flight safely [18]. The battery HMI is going to replace this FMS system to some extent with a new philosophy generated by new certification rules etc. As there are currently no certification rules in place specifically for large electric regional aircrafts, conducting an energy analysis that compares conventional and electric regional aircrafts could provide insight into how differences in energy density between fuels may translate to required display differences.

By examining their various energy capabilities, it is beneficial to compare the energy content of batteries and fuels. Such an energy analyse may provide insightful results. To compare these, they must be converted to the same unit and be compared with similar weights.

$$\begin{aligned} &1[KWh] = 3600000[J] \\ \Longrightarrow \quad &1[J] = 1/3600000[KWh] \end{aligned} \tag{2.1}$$

Since the comparison is going to be made with a smaller aircraft, CESSNA 152, Avgas 100LL will be used as the fuel reference instead of jet fuel. The specific energy of Avgas 100LL, is about 43.5 MJ/kg [19], with a specific gravity of approximately 0.72 [20], which is commonly used as fuel in conventional planes. The energy density of batteries, on the other hand, varies depending on the individual battery technology employed, but is often substantially lower, coming in at roughly 0.100-0.265 kWh/kg for lithium-ion batteries [21], which will be used in ES30. For a specific weight, using Equation 2.1, the energy content in fuel is as follows:

$$\frac{43.5[\frac{MJ}{kg}]}{3600000[\frac{kwh}{J}]} = 12.1 \ [kWh] \tag{2.2}$$

To know how much each litre of Avgas 100LL weighs, and thereby the actual energy content to be used later, the litres are multiplied with the specific gravity according to:

$$1[litrefuel] \cdot 0.72 = 0.72[kg\ fuel] \tag{2.3}$$

3

Methodology

This chapter describes the several methods used in this thesis. It is important to note that this chapter only presents the methodology used, while the actual process of execution is presented in the next chapter.

The methodology is based on interactive design processes originated from the Interaction Design Foundation. It is mixed with a product development process which describes how the process was generated, tested, and refined. The aim is to ensure that the final product meets the requirements and expectations of the end-users, i.e., the stakeholders at the company. The interactive design process involves empathizing, defining, ideating and validating while the product development process includes various stages such as concept development, design development, and engineering used in the interaction design process, see Figure 3.1. Together, these processes provide a comprehensive approach to designing and developing a successful process that meets both user needs and technical requirements for the battery HMI.

Figure 3.1: Visual illustration of the main categorisation in the methodology used for process development that is validated through a battery HMI

3.1 Empathize

User-centred research was the main emphasis of the first stage of the process development where it was important to develop an empathetic grasp of the issue attempted to be resolved [22]. To gain a better understanding of the problem and its challenges, as well as to connect with and comprehend the users, the goal during the Empathize stage was to conduct observations and learn more. This generated the best understanding of the end-users and the issues that are at the root of the creation of the product or service [22]. For example, the focus was on doing research upon relevant literature and on the current stakeholders. This gave a broad understanding and knowledge base of the problems with designing a novel feature such as the battery HMI.

3.1.1 Research

A literature review was conducted to gain a deeper understanding for the topics discussed in this thesis. The literature review process involved a systematic collection and analysis of relevant research and literature related to the problem. This included academic papers, industry reports, case studies, user feedback, and expert opinions. The goal was to gain a comprehensive understanding of the problem and potential solutions.

The literature review served several important purposes. Firstly, it helped identifying the current state of the art and existing solutions. This knowledge helped with avoidance of reinventing the wheel and build upon existing knowledge and best practices. Secondly, the literature review helped identifying the user's needs, preferences, and pain points. By understanding the user's perspective, design solutions could be done so their needs and expectations are met.

Additionally, the literature review helped to identify gaps and opportunities in the problem space. By identifying areas where existing solutions fall short or where there are unmet needs, a focus on developing solutions that address these gaps could be made. Furthermore, the research helped to identify potential design constraints such as technical limitations and regulatory requirements.

3.1.2 Field study

A field study was done which intended to comprehend the architecture and operation of aircraft HMIs. To determine how the displays, controls, and interface components affect aircraft safety, the research adopted an user-centred design approach. The significance of HMIs in aviation safety, the lack of uniformity among various aircraft types, and the requirement to enhance usability served as the driving forces.

3.1.3 User-centred research

Based on found research, semi-structured interviews were conducted to gain a deeper understanding about the employees' experiences and perspectives on the current process at the company to map out areas of improvement. This allowed for flexibility in questioning while maintaining a consistent structure across interviews. Semi-structured interviews include both open and closed questions written in a script to ensure that all interviewees cover the same types of subjects and areas [23]. This structure enables that new lead questions can be asked until new and relevant information appears.

The interviews were made to better understand how current procedures were being used, the reasons why deviations occurred, and the areas where employees' intuition suggested the source of issues were coming from. When the information became clear of which questions to ask whom, it was easier to get useful feedback and suggestions about the hypothesis and methods for improvement.

3.2 Define

The information acquired during the Empathize stage was organised during the Define step. To characterise the main issues found so far, the observations were examined where it was necessary to define the issue and problem statement from a human-centred perspective [22].

3.2.1 Content analysis

Qualitative analysis was used on content that was non-numerical [23]. Three fundamental methods for qualitative analysis were covered: theme identification, data classification, and critical incident analysis [23]. Gaining a general understanding of the data and beginning the search for intriguing elements, themes, recurring observations, or things that stuck out were the initial steps in qualitative analysis. To cover the fundamental methods for qualitative analysis, inductive and deductive methods were used. Analysis was carried out iteratively where themes were identified inductively and then applied deductively to new data.

Inductive content analysis established the categories or codes that would be utilised for the following analysis of all the materials by methodically reviewing a sample set of the materials to be studied [24]. For instance, in a study of transcripts, as key phrases that reflected a common theme emerged, a name for the topic was provided, and then later instances of words or phrases that represented that theme were categorised in accordance with that name [24]. This was the process of turning unorganised data into a map of the key themes in the data, which was described as iterative using a thematic analysis [25].

Deductive content analysis was done by classifying data items using pre-existing theoretical or conceptual frameworks [23]. A deductive method was used for classifying data, whereas an inductive approach was used to identify themes [23].

3.2.2 Concept mapping

A concept map is a technique for making sense of information by connecting several concepts, items, and occasions in relation to a single domain [24]. It offered a framework that aided in visualising the complexity of the system, broke down connections, researched existing connections, and built upon knowledge that were known but sometimes taken for granted about a given system [24]. Based on the content analysis, individual ideas were joined by connecting words to form a concept map. The concept map's strength was that it highlighted new connections within the framework of knowledge that had already been absorbed.

3.3 Ideation

During the ideation stage, the goal was to generate a large quantity of ideas that could then be refined and filtered to identify the best, most practical, or most innovative ones [26]. This process involved various exercises such as sketching, brainstorming, writing down ideas, and considering the worst possible ideas to generate new concepts and solutions for the process development. By engaging in these exercises, new and improved designs, solutions, and products were inspired that met user needs and expectations. In this case, the ideation phase generated different process maps that were evaluated for how well they incorporate human factors in developing a battery HMI.

3.3.1 Concept development and evaluation

The brainstorming session often conducts a various number of combinations that can be utilised. To make an unbiased decision that were truly based on the best concept, rather than personal preferences, decision-based matrices were employed to evaluate the concepts created. For the purposes of this study, a morphological matrix and a Pugh analysis matrix were utilised. These matrices helped to ensure a fair and objective evaluation of each concept to not miss out on potential solutions to the problem.

3.3.1.1 Morphological matrix

A morphological matrix was used to generate new design ideas by combining features from different ideas generated during the brainstorming-session. The morphological matrix expanded the range of potential alternatives for a design and offered an overall strategy. This was done to promote diverse thought to prevent the omission of answers to design problems [27].

3.3.1.2 Pugh analysis matrix

An analytical technique that yielded an ideal notion were the Pugh analysis matrix. Using a matrix-based method to weigh and compare the conceptual designs, the list of options may be narrowed down [28].

When utilised for decision-making, the matrix enabled the ability to pick the best and most practical option from a list of available options generated by the morphological matrix. But to achieve this, the most crucial criteria that would be required to decide among the options were identified, and then the best option based on these criterion were chosen. The most important criteria were obtained through the stakeholder analysis conducted during the user-centred research and define stage.

The matrix was best performed with different concepts as the reference since there were no original process to compare to. The concepts were evaluated and compared with the reference concept based on how well these fulfilled the criteria. If the concept performed better than the reference, a + were given. If worse, - and equally generated a 0 . These were added up and the concept with the highest score were considered the best.

3.4 Validation

In this section, the different validation stages for the process chart will be presented. This was done by expert reviews and a low-fidelity prototype of the actual battery HMI.

3.4.1 Expert review of process

A process validation gave objective data to support that the process was producing the desired results and satisfies the needs of its users. Teams may reduce user error and expensive delays in the product's launch schedule by carefully and completely undertaking verification and validation testing [29] [30].

3.4.2 Battery HMI

To further validate the created process map, a prototype for the battery HMI was conducted through low-fidelity prototyping which were a scaled down version of actual prototyping and involved sketching and story boarding [31]. Advantages with this kind of prototyping is that it was rapid and affordable. Also, that it is possible to test fresh iterations and make immediate modifications, and that it is possible to generate a basic version of the prototype to get feedback from stakeholders, regardless of skill level or expertise [31]. This gave the process map a preliminary evaluation of early improvements and critical areas when used for the actual end cause.

3.4.2.1 Certification differences

One of the key considerations in the design and development of battery HMIs for electric regional aircrafts was the optimisation of energy usage. In this section, the use of energy analysis to accommodate the requirements on the display with regards to fuel were explored. This was beneficial in the aspect of understanding the importance of a reliable battery HMI, and the problems behind the technology.

By conducting an energy analysis of the energy consumption and energy content of a battery versus fuel, valuable insights were gained into the energy efficiency of electric aircrafts, and a better battery HMI was developed where certification might fall short. To conduct an energy analysis, it was important to gather data on the energy consumption and energy content of both battery and fuel. This data was obtained through a small data gathering process.

It is crucial to keep in mind that the display specifications might alter as certification guidelines for big electric regional aircrafts continues to be established. Yet, this energy study shed light on how the disparities between the energy content of battery-powered electric aeroplanes and fuel may be reflected in the displays for pilots.

The procedure for the energy analysis was as follows:

1. The energy content of the fuel and battery energy were calculated.

2. The energy content of the fuel and battery energy to the energy required for the flight were compared.
3. The display requirements for the pilot based on the energy analysis were determined.
4. The regulatory requirements for displaying battery status to the pilot were considered.

3.4.2.2 Usability testing

To test how well the validation of the process turned out using low-fidelity prototyping, usability testing of the prototype occurred together with the Flight test pilot and the human factors team. This was to easily detect the improvement areas with the experts within the field and the end-users.

4

Process and execution

The method used to conduct this study, which was described in the previous chapter, is thoroughly explained in this chapter for the procedure. It will also detail the results of applying this strategy, showing the results of some of the research questions.

4.1 Empathizing research

The empathize stage began with a literature review to identify the relevant knowledge background upon already existing HFI methods, the future of aviation and project management. To understand the problem behind the study even further, a field study and a flight planning session were conducted. To gather further relevant information, a user research study to identify the various stakeholders involved in the design process was made. This involved interacting with different departments within the company to gain a deeper understanding of the current situation and hierarchy. This also gave an insight of previous design philosophies the employees had come across and the existing requirements.

4.1.1 HFI methods

Here, the research found upon HFI methods will be presented. This information gained valuable insights in the difficulties of integrating human factors at other companies or in general. With this in mind, it was easier later to spot the gaps.

Human factors are critical considerations in the development of any system, including the battery human-machine interface (HMI) for an electric regional aircraft [32]. To achieve this, the European air traffic management system states that it is important to integrate human factors considerations throughout the design and development process [32]. They also state that human factors integration is a systematic approach that involves identifying and analysing the human factors relevant to the system, developing, and evaluating design options, and verifying and validating the nal design [33].

A comprehensive understanding of the human factors involved in the development process is essential to optimise the design and development of the battery HMI. This includes identifying potential hazards, assessing user requirements, and considering usability, situational awareness, and workload. As noted by the European air traffic management system, a risk-based approach can be used to prioritise human factors considerations and allocate resources effectively [32]. This involves identifying potential hazards and assessing their likelihood and severity, which can inform the development of mitigation strategies.

The involvement of end-users, subject matter experts, and other stakeholders is critical to the success of the human factors integration process. Collaborative design and evaluation can lead to a better understanding of user needs and requirements and can inform the development of effective design solutions [32][33]. Effective communication and documentation are also essential components of the human factors integration process [33].

4.1.2 The future of aviation

By the year 2050, the aviation sector pledges to have "net-zero" carbon emissions [34]. However, this lofty goal cannot be reached with current aeroplane technology. Future aircrafts' CO_2 emissions will be greatly reduced by using low-carbon propulsion technologies and energy sources like electric and hydrogen propulsion as well as creative solutions to current problems [34]. Advantages with electric propulsion are noise and efficiency but there are also several limiting factors such as energy storage and range [35]. Initial uses of electric propulsion are focusing on industries that are new to aviation, such as urban air mobility and regional air logistics, which are now the purview of road and rail transportation, due to battery restrictions [35]. The majority of commercial aviation's short- and medium-range aircraft will take longer to electrify, while long-haul aircraft are anticipated to continue using liquid fuels [35].

In a partnership with Siemens and Rolls-Royce, Airbus has announced the E-Fan X project, which aimed at creating a hybrid electric propulsion system for commercial aircraft [36]. Despite the 2020 cancellation of the E-Fan X project, Airbus is still committed to researching electric and hybrid-electric technologies for the construction of new aircrafts [36]. It is worth noting that the aviation industry as a whole is actively exploring electric and hybrid-electric technologies [36]. Besides Airbus, other manufacturers, like Eviation aircraft, are investing in electric aviation research and development. Eviation are currently working on their Eviation Alice with nine passenger seats [37]. Advocates of electric aviation expect that Alice and similar electric aircraft will become as widespread as any other kind of transportation [37]. Other aircraft parties, like NASA and Boeing are also investing in a number of companies for the development of electric regional aircrafts [37]. This coordinated effort demonstrates how the industry has come to understand both the need for and the potential advantages of moving towards more environmentally friendly means of air travel [37].

In the near future, an aviation ecosystem that is efficient and sustainable could be developed in large part thanks to ongoing research and development in the area of electric aircraft [37]. However, while certain aspects of battery-powered air travel appear to be nearing readiness, regulation is the most urgent issue for electric regional aircrafts since there has not yet been any precise regulations or guidance presented [37].

4.1.3 Project management

To ensure an efficient workflow, careful planning and appropriate work structure must be in place. There are multiple project planning methods researched today but they all work differently [38]. One more traditional method is the waterfall method, with a sequential workflow that clearly defines the order of tasks [39]. The waterfall method is suitable for projects with low uncertainty or well-defined requirements. It provides an easy-to-predict workflow and is ideal for projects with a clear vision [39]. Another common method is agile product development that is the way of working intensely in cycles [38]. The agile approach is especially appropriate for projects that are done in close collaboration with stakeholders and require flexibility [39]. Being able to adapt and collaborate effectively in cross-functional teams provides a significant advantage in complex and integrated projects, ultimately leading to a reduction in time to market [39]. This method may however be wasteful of resources if the development is predictable or not in the need for cross-functional teams [39].

4.1.4 Field study

Several concerns were addressed through the field study, including the fact that different buttons operated in opposite directions (clockwise versus counter clockwise), leading to confusion and potential errors. Additionally, different units were used in the same display, making it difficult for pilots and crew members to quickly interpret the information. By identifying these concerns and analysing the data, the field study provided recommendations for improving the design and standardising the HMIs to reduce confusion and increase safety.

There were also some concerns regarding the display of the SOC, see Figure 4.1. The electric aircraft only used the SOC and the pilot mentioned that the percentage does not imply the same range in the battery's early life as later, so it made it hard to interpret the actual meaning of, for an example 60% even though it is easy to understand the general meaning.

Figure 4.1: Picture of a battery HMI taken during the field study

4.1.5 Flight planning

As mentioned in the theory chapter, before a flight, a pilot must plan for the energy or fuel consumption needed to execute the flight. By calculating the energy consumption for a small electric aircraft, VELIS Electro Pipistrel, and then calculating the fuel consumption for a small conventional aircraft, CESSNA 152, the energy consumed by both planes for the same trip could be compared. The calculations were made with guidance by the chief test pilot. The trip that was calculated was a 30 miles long trip at 2000 feet above sea level. The total trip consisted of seven stages; Start, taxi out, take-off, climb, cruise, descending and taxi in.

The first step of the calculations was to calculate or assume the length of each step in time. Here, it was assumed a ten-minute start, five-minute taxi out in the beginning and five-minute taxi in at the end. A climb rate of 650 ft per minute was used and a decent rate at 500 ft per minute. With this information, it became visible that climbing to 2000 ft took three minutes and decent took two minutes. The speed was 70 knots and with this, the length of climb and decent could be calculated to know the length of the cruising. The results of the calculations can be seen in Table 4.1 and 4.2.

For the conventional aircraft, the same timestamps were used but here the fuel consumption was calculated instead. This could be done by using the same table but switching out the consumption rate.

Table 4.1: VELIS Electro Pipistrel flight calculations

Sector	Power [kW]	Time [min]	Consumption [kWh]
Start	0	0	0
Taxi out	3	5	0.25
Take off	60	0.5	0.5
Climb	48	2.5	2
Cruise	25	16.35	6.8
Decent	0	4	0
Taxi in	3	5	0.25
Total	139	33.35	9.8

For any type of comparison to be made between the two types of energy consumption, everything needed to be converted into the same unit, Joules (J). By converting the energy and fuel consumption according to Equation 2.1 and 2.3 the results were 3.52 MJ for the electric aircraft and 518 MJ for CESSNA 152, which can be seen in Table 4.2 below.

Table 4.2: CESSNA 152 flight calculations

Sector	Time [min]	Consumption [litre]	Energy [MJ]
Start	10	3	94
Taxi out	5	2	63
Take off	0.5	2	63
Climb	2.5	2.3	72
Cruise	16.35	4.2	132
Decent	4	1	31
Taxi in	5	2	63
Total	43.35	16.5	518

4.1.6 User-centred research

Several in-depth interviews were conducted with key stakeholders involved in the process. The interviews provided valuable insights and perspectives on the current processes, challenges faced, and potential areas for improvement. The interviews were conducted with seven different teams at the company. They were performed face-to-face and lasted between 20 to 70 minutes. Every interview was recorded, with consent from every interviewee, and then transcribed into text for further analysis. The interview questions can be found in Appendix A.

4.1.6.1 Interview take-aways

By analysing the rich and diverse data gathered from the interviews, a deeper understanding was gained of the complexities and nuances of the process development, and identified actionable recommendations that could help enhance efficiency, quality, and effectiveness. The insights presented in this section provided a robust foundation.

It is important to note that, in order to maintain integrity and confidentiality, not all of the answers provided will be listed here. Instead, they will be utilized solely as a tool for the development of the process. However, a few of the important highlights from the interviews will be presented as citations below.

> The purpose of human factors is to guide support and confirm every aspect of the human interface

> Human factors need to understand how the operation is envisioned to display it

in a meaningful way

Human factors ideally considered from the beginning but needs to be more flexible

Human factors needed as early as possible

Rest of the company needs to take human factors more seriously

Human factors have assumed responsibility for the flight deck when that is not the case at all

Human factors is typically one of the least prioritised departments

We need to sort out who is responsible for what in a reasonable way.

Need traceability and easy documentation

4.2 Define

When the interviews were finished at the empathize stage, the transcriptions were examined, and the responses were organised and examined using sticky notes in an inductive and deductive way. This stage was crucial because it aided in identifying the most important insights and classification of the data in a way that was clear and intelligible. Here, recurring themes and patterns in the data were identified. The exact interview responses will not be presented due to confidentiality and integrity.

4.2.1 Content analysis

Based on the interview responses, the answers could inductively and deductively be categorised into ten categories:

1. Current Roles: What roles do they or other teams play in the process
2. Incorporation of human factors: When and in what ways should human factors be involved
3. Relationship with others: How they described the current level of collaboration between teams
4. Routines: Feedback on the current process, or suggested ideas for improvement, with a focus on a smaller scale

5. Communication: What is the current process for passing information between teams, and suggested improvements
6. Resources: Feedback on the current availability of resources or potential improvements of resources
7. Meetings/FDWG: General comments about meetings, whether positive or negative, and especially regarding the FDWG collaboration
8. Flexibility and speed: Feedback on the current level of flexibility and speed, and suggested ideas for the ideal states
9. Knowledge: Feedback on their knowledge of the current process, others' work, and technology
10. Goals: General aims for the process in development, and suggestions for establishing common goals within the company

4.2.2 Concept mapping

The concept map is exploring the issue of "No proper involvement of human factors". This shows the interrelated issues that arise when human factors are not given sufficient attention in projects. The map was created based on the interviews with stakeholders and experts in various fields from the Empathize phase, but also on general research upon HFI in other scale-ups.

The map consists of the ten topics found in the content analysis. Each topic represents an area of concern that generally can lead to problems when human factors are not properly considered and are displayed in yellow in Figure 4.2. The grey areas are identified reasons and proof for the major topics of concern.

Figure 4.2: Concept map that clarifies the interconnections among the current issues commonly apparent in scale-ups

The relationships between these concepts were then determined by looking for similarities, differences, or cause-and-effect relationships. For example, communication difficulties usually hinder a well-established information flow, and lack of resources affects flexibility and speed, which in turn affects each other. Additionally, knowledge and awareness of others' work was found to improve communication and working relations with other departments, while FDWG meetings provided a platform for improving communication, understanding of distinct roles, and goal alignment, but hinders flexibility and speed.

Finally, the concepts were organised in a logical and meaningful way to create the concept map. This map serves as a visual representation of the key themes and their relationships and was used as a tool to better understand the process for the optimal timing of human factors involvement. It highlights the importance of effective communication, resource allocation, and goal alignment in achieving success in this process, which is seen as one of the key identifications in this study.

Overall, this concept map demonstrated the complexity of the process for the optimal timing of human factors involvement and the need for careful consideration of multiple factors. It was used to guide decision-making, identify areas for improvement and to understand the root of the problems existing today.

4.3 Ideation

Here the concept generation and evaluation will be presented beginning with a brainstorming session. This is followed up by a morphological matrix together with a Pugh matrix.

4.3.1 Brainstorming

The brainstorming session followed a structured process to ensure that all ideas were considered and evaluated based on their potential to meet the process goals with the design requirements fulfilled. The problem definition phase involved defining the design problem and its goals, identifying the target stakeholders, i.e., the responsible department, and specifying the context of use. The problem definition phase provided a clear understanding of the process constraints and helped the generation of ideas that were relevant to the problem.

The idea generation phase involved generating as many ideas as possible, without judgment or evaluation. The team encouraged all ideas of the placement of the stakeholders at different segments, which could spark creative thinking and lead to innovative solutions for requirement fulfilment.

After this session, a greater understanding of potential combinations and requirements were obtained. The draft of different concepts was mapped out to identify the main points and opportunities for improvement. This allowed a development for a more comprehensive strategy for addressing user needs and enhancing the overall process offering. By taking a holistic approach, insights that may have been overlooked otherwise could be uncovered. This information was invaluable as the process development moved forward with refining the process map to enhance the stakeholder experience.

4.3.2 Concept development

In the following section, the concepts that were generated based of the brainstorming session will be presented. Please note that these concepts are still only brainstormed and are therefore subject to change in later final concepts. They are not final and may not include all the requirements that have been stated. However, the key considerations with the concepts will be described and explained.

4.3.2.1 Process concept A

First process generated were Concept A. The process uses turning points that direct the information or movement of actions. The efficient and successful execution of each phase allows for the orderly flow of work. The flow chart acts as a helpful visual depiction of the process, allowing stakeholders to comprehend the general organisation and relationships among various parts. The aim is to ensure clear communication and smooth progress between stakeholders throughout the entire process. The process enables the waterfall method with some agile style with loops.

4.3.2.2 Process concept B

The second process, Concept B, is a flowchart with a horizontal flow with a continuous flow from left to right. The flow based on the information and knowledge that each actor contributes with. The flow chart illustrates a knowledge-based notion by showing how different knowledge domains are related and used in the process. It emphasises the dissemination and synthesis of knowledge from many sources to aid in the making of well-informed decisions. The flow chart aids in the comprehension of the knowledge-based process by showing how information, knowledge, and insights move across several phases. The diagram provides a visual depiction of the knowledge integration.

4.3.2.3 Process concept C

The third process, Concept C, is a flowchart with the focus on decision making. A process's interrelated decision points are depicted in the decision-based concept flow chart. It depicts the standards, constraints, and options that influence decision-making. Each decision point provides options, enabling stakeholders to select the best course of action based on predetermined criteria. Stakeholders may ensure relevant knowledge and supporting efficient decision-making by following the flow chart and understanding the logical evolution of choices.

4.3.3 Evaluation of concepts

The idea screening phase involved evaluating and selecting the most promising idea based on their potential to meet the goals, so all the teams involved have their needs included. The team used a set of criteria, including feasibility, desirability, and viability, to screen the ideas. The team also considered the potential impact of the ideas on the user experiences. This was to make sure that the human factors and operation requirements are well determined at an early stage to reduce eventual costs of re-doing the design at a late stage. The team also considered the feedback from the stakeholders, identified at the interviews, to improve the process concepts and refine them further.

The concepts produced during the brainstorming session were assessed in a more organised and methodical manner utilising both morphological matrix and Pugh matrix, allowing for a more thorough examination and comparison of various choices. By using this method, you make sure that the study's ultimate concept or answer is the best suitable for the given issue, see Table 4.3. This was also made to not overlook potential solutions just because they were not thought of before.

Table 4.3: Morphological matrix

	Method 1	Method 2	Method 3
Display Time	Stages	Left to right	Top to bottom
Involve Actors	Visualised	Somewhat visualised	Not visualised
Show Paths	Loops	Back flow	Decision based

The process itself was seen as static, with a focus on developing the visual aspects. To achieve this, three functions of a flowchart were defined, named Display Time, Involve Actors and Show Paths. Three different solutions were defined for each of these functions, resulting in a total of 27 possible combinations. However, only two more concepts were generated Combination 1 and Combination 2.

After the morphological matrix, a Pugh evaluation matrix was used to compare and evaluate the five different concepts. The comparison was made based on a set of criteria, see Figure 4.3 and 4.4, such as clear decision motives and few crossover paths.

Figure 4.3: First iteration of the Pugh matrix using Concept A as reference

Figure 4.4: Second iteration of the Pugh matrix using Combination 1 as reference

First Concept A was used as the reference which resulted in Combination 1 receiving the highest score. Next Combination 1 was used as reference which led to a similar result. This further ensured that Combination 1 was the most promising concept for further development, see Figure 4.5.

Figure 4.5: The process Combination 1 after evaluation. Disclaimer: This process chart is just visualising the idea of the concept and might miss some aspects due to confidentiality. Therefore, the actual detailed process map is not included.

4.4 Validation

The process map created was first validated through an expert review and then by a display draft doing low-fidelity prototyping for the battery HMI. This was to see the performance of the process and evaluate potential improvement areas by following the process.

4.4.1 Expert review of process

To make sure that the suggested process was reliable, effective, and in line with the company's best practises, expert validation of the process chart was a crucial first step of the validation. To do this, the key stakeholders from the company were gathered, who were requested to analyse the process chart and offer input on its advantages and disadvantages. They were asked to review the process chart in detail and to provide feedback on several aspects, including the clarity, the feasibility of the proposed process, and any potential areas for improvement.

Most of the experts noted that the suggested process was well-structured, simple to follow, and provided for traceability. Overall, the expert panel's opinion was positive. They valued the precise assignment of duties and the use of visual aids to make the process flow more understandable. The process chart was also noted as being usefully descriptive without being unduly complicated or onerous.

Some areas for improvement were identified, such as potential need for additional testing or validation at certain stages of the process. Some words were also exchanged, e.g., parameters instead of requirements, to reduce confusion and the another team were identified to be included at the beginning and at the end to make sure that the display development is aligned with potential regulations. These suggestions were carefully considered and incorporated into the final version of the process chart, see Figure 5.1.

4.4.2 Process validation through a battery HMI

Here, the various steps involved in the validation by conducting low-fidelity prototyping on the display will be described. This first involved doing an analysis to spot potential certification differences that could differ from conventional CS25 aircrafts and thereby affect the design. Then, a design workshop with key stakeholders and gathering parameters to test the effectiveness of the proposed process were conducted. The objective of this phase was to assess the ability of the process to deliver a successful outcome in a simulated real-world scenario.

4.4.2.1 Certification differences

The earlier done research claimed that there has not yet been any certification or precise regulations or guidance for electric aircraft [37]. The display generation stage therefore included a comparing analysis of electric aircrafts and conventional regional aircrafts' energy content received from the fuel to draw conclusions upon certification differences. This since batteries, as opposed to fuel, have a lower energy level, which is what powers electric aeroplanes. Using the energy comparisons done in 4.1.5 Flight Planning, the energy consumption for the same type of flight of the battery is substantially lower, having a value of 3.52 MJ, while fuel has a value of 518 MJ.

Since there is a difference in energy consumption, this will affect the range since the energy content of batteries are drastically lower, having a value of 0.2 kWh [21], while fuel has a value of 12.1 kWh for a specific weight, using Equation 2.1. The cycle life of a battery will also mean that it will deteriorate in an unpredictable way, meaning the fuel level left is hard to calculate using an FMS. In the comparison of certification, the certification requirements for each kind of aircraft were analysed, paying particular attention to how they manage safety issues with the corresponding energy systems. The most important gap of certification for CS-25 classified aircrafts is the following requirement for the propulsion systems.

- Fuel indication systems providing the flight crew a constant display of the entire amount of fuel that is available on board [4].
- Fuel indication systems able to communicate to the flight crew the amount of available fuel in each tank [4].
- Any tank and/or collecting cell that should not run out of gasoline should provide a flight deck warning [4].

Since the aircraft must offer data that will enable comprehension of the remaining flying time and/or range to give the pilot relevant and trustworthy information about the status of the energy storage system. Due to the numerous variables and non-linear behaviour of energy depletion, it is assumed that the pilot's ability to predict the remaining flight time based on the current energy level observation is limited or even impossible. Therefore, the aircraft must provide a more consolidated and straightforward set of indicators to help the pilot understand the situation and its trends, for example:

1. Predicted surplus State of Function (SOF) at destination.
2. Estimation of the State of Health (SOH)
3. SOC estimation
4. Estimation of the remaining total energy

According to the previous suggestions, parameters that are independent of one another and important for the pilot's ability to make decisions should be depicted in a fashion that helps the pilot comprehend each parameter's unique state and behaviour. This is since battery energy content is lower than for fuel, but also that a SOC of 100% does not generate the same amount of range based on the SOH.

These are important considerations and potential not yet explored certification statements that deviates from the rules upon conventional propulsion.

4.4.2.2 Battery HMI generation

The low-fidelity prototyping began with a parameter gathering from all the relevant departments. All the parameters from a real-world scenario were not listed since the prototyping is low-fidelity but some of the most important ones were considered for a fair validation. They will not be listed due to confidentiality but the general meaning is included in the prototype.

These were inserted in the flow chart and the prototyping began. For example, instead of the typical 12-month development process for a novel feature or function, it would now complete it in just 12 hours, with each hour representing a month. While the real-life scenario time frame may be difficult to anticipate, this condensed time frame provides a clear and easy-to-follow framework for the progress in the process.

To conduct the workshop, a curated group of employees participated in a scaled-down version which lasted approximately two hours. The parameters and constraints collected from the previous stage were listed on a whiteboard together with some constraints, and a representative display was placed to visualise the final product's size accurately. Next, each participant expressed their design ideas by drawing pictures on sticky notes based on the gathered parameters, and potential certification differences which were placed on top of the representative display. There were some challenges with alignment and getting a holistic view. For an example, since the thesis only focuses on the battery displacement, none of the other parameters that is important for flight were considered. This made it difficult to make an approximation of the actual space reserved for the battery status and the other correlated alerts.

After simulating the next step, which was the modelling, the display supplier's design proposal was followed, and the possible certification parameters were kept in mind while representing the design through sketching and basic digital mock-ups. To create a design prototype, PowerPoint was used with an existing blank display model as a template. Throughout the iterative process, human factors were consulted with to develop a mature design recommendation. Before entering the final stage of design review, the recommendation underwent a small final validation to ensure it met the previously established parameters.

The resulting display from the validation process can be seen in Figure 4.6 and 4.7. The small display next to the prototypes represents the design proposal/philosophy of where the different information is to be displayed.

Figure 4.6: Primary flight window (PFW) and multi-functions window (MFW). Disclaimer: the content of these displays is for illustration purposes and do not represent the actual design to be certified.

On the display's second page, as shown in Figure 4.7, the pilot can access the systems information window (SIW) and alerts (CASFW) together with the previously shown MFW according to the small design proposal/philosophy visualised next to the display. The SIW provides an overview of the SOH and the status of the various components that drive the aircraft.

Figure 4.7: Systems information window (SIW) and alerts window (CASFW) together with the multi-functions window. Disclaimer: the content of these displays is for illustration purposes and do not represent the actual design to be certified.

Usability testing was conducted on the HMI prototype during the design review stage in consultation with human factors. The primary focus of the testing was to optimise the prototype's colouring and positioning to improve its interpretability for pilots. Testing was carried out in accordance with the established process.

Following the initial design review, a simulated flight was conducted in a test facility to compare the design with a preliminary one already installed, see Figure 4.8. This allowed assessment of the interpretability and feature sizing of the design in a simulated real-world scenario.

Figure 4.8: Flight simulation with display next to the preliminary one. Disclaimer: the content of these displays is for illustration purposes and do not represent the actual design to be certified.

5

Results

The deliverable for the aim of the study will be presented in this chapter which is the actual final process chart presented in Figure 5.1 below. It provides a comprehensive visual representation of the development of the novel and complex function of the battery HMI. The process chart was developed to meet the requirements of stakeholders for a more traceable flow with clearly defined tasks.

Figure 5.1: Final process map. Disclaimer: This process chart is just visualising the idea of the end concept and might miss some aspects due to confidentiality. Therefore, the actual detailed process map is not included.

6

Discussion

We will examine the findings and analyses in this discussion chapter, making links between them and the study's primary objectives and open-ended research questions. Therefore, this chapter will discuss the chosen methodology, results, and the interplay between energy consumption and human factors in electric regional aircrafts, highlighting design considerations for battery density and cognitive workload, as well as considerations for future work in this field.

6.1 Methodological approach

The methodology used in this thesis offers a comprehensive approach to designing and developing a successful process that meets both user needs and technical requirements for the battery HMI. By combining interactive design processes and a product development process, the methodology provided a structured framework for generating, testing, and refining the process to ensure that it met the requirements and expectations of end-users. This approach allowed us to gain a deep understanding of the users' needs and preferences, as well as to generate a wide range of ideas and concepts that were evaluated and refined based on user feedback. By involving end-users throughout the design process, the resulting process was tailored to their specific needs and preferences, leading to a better user experience and higher user satisfaction.

Another key advantage of this methodology is its use of a product development process, which included various stages such as concept development, design development, and engineering. This process ensured that the final product not only met the user's needs but also evaluated if the process ensured that the technical requirements and constraints could be fulfilled. By testing and refining the process at each stage, we were able to identify and address any technical issues, leading to a more robust and reliable final process.

However, it is worth noting that this methodology requires a significant investment in time, resources, and expertise. It involves multiple stages and requires collaboration and communication among various stakeholders, including end-users, designers, engineers, and project managers. It is also quite time consuming when validating the results by prototyping the feature, even if it is low-fidelity. Throughout the development of the process, close collaboration with the human factors team allowed for continuous evaluation and integration of their input at different stages of the study. By involving the human factors team in this way, their expertise and recommendations were effectively incorporated into the process where they were deemed most important, which fits well into the main purpose of the thesis.

6.1.1 Low-fidelity prototyping as validation

To meet the acceptable means of compliance parameter set by certification, we opted to utilise the pre-existing design of the small electric aircraft, VELIS Electro Pipistrel, which had been previously studied during the field study outlined in subsection 4.1.4, as a reference for our own design. By doing so, we were able to gain insight into how the analysed certification differences could be translated into the display design. Thus, the display's design was able to include the essential certification standards effortlessly while still providing the pilot with a user-friendly interface. By using this strategy, we were able to shorten the creation process to fit into the tight period of time and make sure the result demonstrated compliance with the certification regulations along with the parameters.

The final usability testing implied that the new design was easier to understand and had a more comprehensible sizing than the existing design. This indicates that the process can successfully incorporate Human Factors considerations and design processes into the development of the HMI. The design is however not complete due to shortcomings in knowledge about what will be needed in the final display. The new battery HMI received positive feedback overall, suggesting that the process was able to satisfy multiple teams expectations and requirements.

Throughout the process, valuable insights were obtained, and significant knowledge was gained from each step. Low-fidelity prototyping played a crucial role in providing insights and identifying areas for improvement, particularly regarding detailed descriptions and decision-making processes. Challenges arose during the design workshop and modelling stage due to questions about timing, decision-making freedom, and interpretation levels. Incomplete information on supplier philosophy and requirements further complicated certain stages. While the early stages of low-fidelity prototyping yielded significant insights and validation, extracting meaningful learnings became more difficult as the validation progressed. It was challenging to determine if difficulties originated from the process itself or the lack of information from previous steps. Conducting larger-scale testing may offer additional insights in later stages, but small-scale testing provided the advantage of evaluating the process independently of individuals' abilities and experiences.

In the modelling stage, notable uncertainties emerged, such as the level of decision-making authority between the design workshop and the modelling stage. Determining the necessary level of detail for an accurate model representation proved challenging, particularly without knowledge of the supplier philosophy or access to suitable software. Due to the limitations of low-level modelling, few iterations were possible during testing, making it difficult to anticipate flaws and subsequent improvements for real-life scenarios.

While the low-fidelity prototyping effectively validated some process steps and provided valuable insights early on, the usefulness of the takeaways diminished later in the process. This may be attributed to the executioners' limited knowledge of human factors, certification requirements, and batteries. However, the feedback obtained from the testing helped identify areas for improvement in the process, which can be pursued in future work.

Analysing the results of the low-fidelity prototyping in terms of incorporating human factors into the final product proves challenging. However, low-fidelity prototyping may outperform full-scale prototyping in shedding light on both the benefits and drawbacks, thereby magnifying the weaknesses of the process and making them more visible.

6.1.2 Energy consumption and human factors

The flight planning exercise revealed significant differences in energy consumption between the two aircraft types. Although the calculations were based on smaller aircrafts subject to different certification rules than the company's aircraft in development, the general differences were assumed to be comparable. The most notable difference was observed during take-off and descent, where the electric aircraft consumed zero energy while the conventional aircraft did not. Another key difference is the battery density, as there is a common misconception that electric aircrafts were impossible to fly due to the low energy density of batteries. This results in a need for excessive batteries, which in turn makes the plane heavier and limits its range. These factors require a new mindset and mental model for how energy consumption works in electric regional aircrafts, and it is vital that human factors are considered in the design process to prevent slips and knowledge errors and thereby increase error potential and safety impacts.

Given the novelty and higher complexity of this project, there is a greater reliance on human factors integration to account for cognitive aspects and physical ergonomics. This includes assessing workload during different flight stages, particularly as the battery HMI could increase cognitive strain and workload if the pilot needs to interpret the battery state.

The Swiss cheese model suggests that accidents occur when multiple system failures align, and in this model, the pilot can be seen as the last line of defence. It is therefore important that the HMI is developed with human capabilities and limitations in mind to prevent potential alignment of failures. Due to the novelty of the technology compared to traditional aircrafts, it is important to train pilots accordingly to understand the characteristics of an electric propulsion system on an aircraft.

When exploring a new area of the aviation industry and being in the forefront of electrifying aircrafts, there is not much guidance in previous work or regulations. The way that the certification rules are written, they are not applicable directly on electric aviation. This does not mean that no rules will exist, but rather that the rules must be estimated before they do. It is a crucial part of developing the battery HMI to look at the excising regulations and understand the purpose to know what is needed from a battery HMI.

To develop an optimal battery HMI, it is necessary to carefully analyse the behaviour of the battery and understand how pilots interact with the HMI. This analysis must also consider the existing certification rules for aircraft HMIs and how they are interpreted in today's aircrafts. By establishing a connection between these factors, we can estimate future rules and regulations that will affect the design of the battery HMI, and ultimately create an user-friendly and compliant system for electric regional aircrafts.

To achieve this goal of incorporating the new characteristics of electric propulsion into the battery HMI, cross-team collaboration is crucial in early stages of the development. The novelty, complexity and integration of HMI is central in the development of the process since this determines the rigorousness of the process and the extent of collaboration within the company.

6.2 Results

The final process chart is the product of multiple iteration sessions based on the preferences of the key stakeholders, but mostly human factors. Its goal is to operate as a decision support system to enhance the workflow. It is constructed around the produced list of needs. The results are a process chart that incorporated human factors principles to enhance usability and reduce errors. The process was broken down into smaller, more focused, and manageable steps, with each task defined and accompanied by detailed instructions. There is also visual cues and colour coding to help users easily identify essential information and reduce the risk of errors by creating layers, like in a Swiss cheese model.

The final process chart delineate the responsibilities of the stakeholders. Compared to process concept A, the new process Combination 1, developed in the morphological matrix and evaluated in the Pugh-matrix, has an advantage in that it facilitates traceability right from the start and incorporates information flow from process Concept B. Specifically, it outlines the specific documentation requirements for each department at stage zero and provides a list of requirements that all parties must fulfil, which was a wish brought up at the interviews. Overall, these features make the process more transparent and streamlined before the approval meetings.

The resulting process is the culmination of the best features from all three concepts, carefully curated and integrated to create a comprehensive and effective workflow. By leveraging the strengths of each concept and eliminating any superfluous or redundant elements, the process has been optimised for efficiency, clarity, and quality. For instance, one concept emphasized the significance of documentation, while another underscored the need for clear communication and accountability. By incorporating these features into the final process, every participant is aware of their responsibilities and has the necessary checklists to perform their tasks proficiently. This ensures that the workflow proceeds smoothly, with everyone working together towards the project's objectives.

The features in the process chart enables a more efficient development process because it minimises the risk of miscommunication or errors that can occur when different departments or individuals are unclear about their responsibilities or expectations. With a clear understanding of the requirements, parameters and expected outputs at each stage, team members can work more effectively and with greater accountability, reducing the need for time-consuming and costly rework.

Moreover, the enhanced traceability provided by this process concept enables better quality control and continuous improvement. By clearly identifying the sources of inputs and outputs at each stage, it becomes easier to pinpoint any issues or areas for improvement. This, in turn, enables teams to quickly address any problems and make any necessary adjustments to the process to optimise outcomes.

Ultimately, the benefits of this approach go beyond just streamlining the process and improving quality. It also fosters a culture of collaboration and shared responsibility, where each team member understands their role and how it contributes to the overall success of the project or organisation. As a result, it can lead to better job satisfaction, greater engagement, and a stronger sense of collective purpose, which can be one of the main strengths of this process.

When involving many different departments in many stages of the process, it is essential to ensure that everyone is on the same page regarding the goals and objectives. This requires a significant amount of time and effort to align everyone's expectations and priorities in stage 0 and stage 1, which can prolong the process. Moreover, involving different people can lead to conflicts and disagreements, which can further slow down the process. For instance, colour preferences and how the battery level is displayed may vary in opinion in the different departments. In such situations, it is necessary to strike a balance between different perspectives, which can be a challenging task.

However, it is essential to involve different stakeholders to ensure that the product meets the expectations and requirements of everyone involved. To achieve the desired outcome, clear communication, effective collaboration, and an evidence-based flexibility to compromise are essential. However, this goes beyond simply establishing a working process; it involves cultivating a working culture and an established company. Since this topic is beyond the scope of the thesis, it cannot be explored in depth.

In addition, the final process provides a clear and visualised road map for when to involve the human factors team, with each department clearly involved at specific stages. This clear demarcation ensures that no phase can proceed without the necessary consultation and input from all relevant parties. This was identified as a key improvement needed in the current way of working and has been incorporated into the final process as one of the main takeaways from the user-centred research to improve efficiency and communication.

6.3 Future work

The thesis has explored the integration of human factors in the development of the flight deck, the energy density's effect of the development of HMI and whether a low-fidelity prototyping approach is effective for validating a developed process. To succeed in answering our research questions in the time frame, some limitations had to be made for the purpose of optimising the process even further. We will therefore bring up some suggestions for future work in this area that could contribute to a better understanding of the subject.

The time constraint has impacted the scope, and if the time would not have been so sparse then the validation process could benefit from a more extensive form. Since the low-fidelity prototyping gave good input and learning's early in the stage, there are reasons to believe that a more thorough testing could go even further and give greater input later in the process. Therefore, further work could be to make a slightly more extensive validation to gain more input for the later stages in the process. The next step would also be to include more people in the testing to see the process from each team's perspective. This could contribute to a more detailed validation and more weaknesses could be found and improved. A more extensive testing could also involve the testing of the process usability, to see how well the users interpret the flowchart and the guidelines.

Since this project focuses on the HFI of the process, the final process is seen as the HF ideal with some inputs from the user-centred research. However, to gain more insights there would be an advantage in conducting another round of interviews to gain more specific information. Since the outline of the process already exists, this would be a good opportunity to ask more specific questions to further improve the process to meet the goals of all the end-users.

With more time and a deeper understanding in Human factors and certification, the documentation could be addressed further. The documentation was identified as an important aspect of the process and could therefore be an interesting and crucial part to explore deeper to properly ensure continuous and high-quality documentation.

This thesis had the limitation of not discussing the approval meetings and hence limiting the scope of the process start and finish. This could be another area to explore further. To optimise the process further, the overall structure of the company could be explored to find the catalyst of the process. The current process ends with the approval meeting which is not discussed in great depth, these meetings are however discussed and mentioned in multiple interviews which could imply that there could be some benefit in exploring this in greater depth and continue the process after as well.

Additionally, as of now, the process is limited to handling battery HMI and other software HMIs. The possibility of widening the process to be able to manage other types of HMI development could be interesting to explore as further work. By widening the process, it could be more universal and be relevant for all HMI development of novel features and functions. By doing so, the process could become vague and more difficult to follow for specific tasks. Therefore, the subject should be explored further before being executed.

This is a company that is currently growing and establishing its organisational culture. In order for the process to be relevant and beneficial to the company, the process will need to continue to develop along with the company. With a constantly developing and dynamic work structure, the process will need to adapt as well. The potential adaptation for the process has yet to be explored and therefore, left for future work.

7

Conclusion

The aim of this study was to streamline the process up until the approval meeting for optimising the way human factors is incorporated in the development of the battery HMI. In this chapter, the research questions will be answered with help from previously conducted chapters:

- How can the integration of human factors be improved in the development of novel features in the flight deck?
  By implementing a clear and structured process that outlines which stakeholders to consult and involve, various departments, including human factors, have integrated their input into the creation of novel features more easily. This approach ensures that all relevant perspectives are considered before progressing to the next phase, leading to more effective collaboration and better communication. Furthermore, by utilising visual aids to clearly communicate the process, team members are better able to understand their roles and responsibilities, reducing confusion and streamlining the development process.

- How does the energy density of batteries compared to fuel affect the design considerations of the battery HMI for electric regional aircrafts?
  The lower energy density of batteries compared to fuel is a significant factor in the importance of precise energy understanding and calculations in electric regional aircrafts. With limited range, managing energy consumption becomes crucial, placing a greater strain on pilots and the plane's ability to estimate and supervise energy usage. Hence, in an electric regional aircraft, the HMI between the pilot and the plane plays a critical role and requires careful design to ensure that it does not overcomplicate the meaning of the SOC and other critical energy-related parameters so it follows the certification rules on CS-25 classifies aircrafts regarding how to display fuel levels.

- Is low-fidelity prototyping an effective way of validating the effec-

tiveness of the process?
Low-fidelity prototyping allowed us to obtain important insights into the process' essential components, revealing areas that may be worked upon and reinforcing some features of the approach. Further evidence of the value of low-fidelity prototyping for process validation comes from the feedback gathered during the prototyping phase, which was particularly useful in identifying areas for further research. Although early low-fidelity prototyping successfully validated several process stages and offered insightful information, the value of the takeaways faded as the process progressed. Nonetheless, the test results helped indicate areas for process improvement, which may be addressed in subsequent work. Therefore, low-fidelity prototyping may perform better than full-scale prototyping in highlighting both the advantages and disadvantages in a short period of time, thereby amplifying and making more obvious the process' flaws.

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A

Interview questions

Hello!
We are doing a master thesis on Human factors integration in the development of the flight deck. We are trying to ensure an effective process for novel features but due to the thesis we are focusing on the battery display. More specifically, we will focus on the battery management HMI. We will begin with asking about the current development process, and then we will move over to ideas and improvements.
Is it ok to record the interview?
*Bear in mind HMI in aviation is new to us, if you could be as descriptive as possible w/o going too deep into terminology we would appreciate that.
If you need to explain something visually, we have a pen and paper if you would like to map out the process and further explain your mental process.
We will try to keep the questions open and feel free to talk freely about anything that comes to your mind. The purpose of this interview is to gain insight into the different stakeholders and map out the process for our understanding.

The first questions are asked regarding the current process, and keep in mind that all questions are aimed towards the development of a battery HMI.

1. In developing a battery HMI, what are your roles and responsibilities?
    a. (Where does your scope in the team begin and end)
2. Who do you consider that the other stakeholders within the company are?
3. What are your current working processes? Describe what is the input and the output of your work for the battery HMI.
    a. What information do you receive from others and what do you then deliver forward?
4. In which part of the process do you involve others, and especially HF?
5. How do you involve HF? What purpose does HF have for you?
    a. In this process, do you ever contact HF and how do you do that?
    b. What is the purpose of human factors?

Now we move on to challenges and ideas

1. Can you describe your experience with the current process in your team? Are there any areas you think could be improved or changed?
    a. What is the workflow?
    b. Who should talk to whom to make the workflow efficient?
2. From your perspective, do you have any thoughts on the other stakeholders beyond your team, who should be involved and what should their responsibilities be?
    a. Based on the stakeholders you mentioned before, are there anyone you think should or shouldn't be involved?
3. In your opinion, when should human factors be ideally considered in the development process
    a. How could the process ensure that it's effectively integrated into
    b. Should any team, in your opinion, have main responsibilities for the incorporation?
    c. What are the main challenges of incorporating HF today?

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