

Article

What Do You Need? Information Requirements and Task Analysis of (Future) Advanced Air Mobility Pilots in the Emergency Medical Service

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Abstract: In the domain of Advanced Air Mobility (AAM), Simplified Vehicle Operations (SVO) promise a reduction in handling complexity and training time for pilots. Designing a usable human–machine interface (HMI) for pilots of SVO-enabled aircraft requires a deep understanding of task and user requirements. This paper describes the results of two user research methods to gather these requirements. First, a traditional Helicopter Emergency Medical Service (HEMS) mission was examined using a Hierarchical Task Analysis (HTA). The findings were used to formulate a theoretical HTA for a single-piloted electric Vertical Take-Off and Landing (eVTOL) system in such a scenario. In the second step, qualitative interviews with seven subject matter experts (pilots and paramedic support) in HEMS operations produced vital user requirements for HMI development. Key findings emphasize the necessity of a simplified information presentation and collision avoidance support in the HMI.

Keywords: advanced air mobility; urban air mobility; human factors; human–machine interface; qualitative research; hierarchical task analysis; expert interview; helicopter emergency medical services



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1. Introduction

Advanced Air Mobility (AAM) and Urban Air Mobility (UAM) are expected to become growing industries in the coming years [1]. One new aircraft class for this type of aviation is the electric Vertical Take-Off and Landing (eVTOL) system. In AAM eVTOLs, some modes (e.g., take-off and landing) are comparable to conventional VTOLs, while others (usually cruise flight) are significantly different [2]. Currently, regulating agencies worldwide are in the process of standardizing the requirements for eVTOL aircraft. For the human factors aspects in the design of such systems, manufacturers are referred to existing legislation from traditional aircraft classes [3,4].

However, with such a substantially new design, it is sensible to consider how pilots interact with the system. One new interaction paradigm in AAM is Simplified Vehicle Operations (SVO) [5]. In this concept, the pilot's input is further abstracted from the effect on the propulsion and control surfaces of the aircraft than in conventional “fly-by-wire” systems (such as in Airbus aircraft [6]). Therefore, a human–machine interface (HMI) redesign is necessary for successful SVO [5].

One way to systematically (re-)design the HMI is following a user-centered design (UCD) approach such as ISO 9241-210 [7]. The first step in this design process requires “understanding and specifying the context of use” and afterward “specifying the user requirements” [7]. The research described here focuses on the scenario of eVTOL use in Helicopter Emergency Medical Services (HEMS). Academic researchers, HEMS non-governmental organizations (NGOs), and eVTOL manufacturers are currently exploring using eVTOLs to rapidly transfer emergency doctors [8,9].

This paper describes two qualitative methods that were used to gather task and user requirements for such a scenario. First, a Hierarchical Task Analysis (HTA) was compiled. Previous results from this analysis were already presented in [10]. Second, qualitative interviews with professional helicopter pilots and a crew member from mountain rescue services were conducted. With these experts' domain knowledge, it is possible to deduce which information is necessary for the successful execution of an Emergency Medical Service (EMS) mission.

2. Existing Research

To date, understanding human factors challenges within the domain of AAM and UAM has yet to gain substantial traction. Many studies in the field focused on the technical challenges and general development of suitable aircraft for AAM or performed high-level, "sociological-driven" analyses on passenger flows, etc. [11]. Nevertheless, a limited amount of studies apply to HMI design in modern aircraft and AAM in particular. The following section presents a (non-systematic) overview of studies that relate to the "human-within-the-loop" [4] perspective of controlling small aircraft. Afterward, relevant literature on the role of humans in the control of SVO aircraft in the HEMS domain is explained.

2.1. HMI Design Aspects for Small Aircraft

One project that incorporated early ideas of SVO but did not label it as such was myCopter [12]. Within this project, an interdisciplinary group of researchers investigated the possibilities and requirements necessary in the implementation of "Personal Aerial Vehicles" (PAVs). Those vehicles were envisioned as a means of daily commuting or as a general personal vehicle (i.e., comparable to the classic sense of a "flying car"). One published result from this research was a comprehensible review of features and options for designing an HMI in such a type of aircraft [13]. This review includes the suggestion to explore task-dependent displays and obstacle representation for (future) PAVs.

Much of the later research on human factors aspects in UAM mainly focused on the user experience (UX) and usability of autonomous public transport eVTOLs. For example, multiple workshops on this topic were conducted at the AutomotiveUI conferences between 2021 and 2023 [11,14–16]. Another study focused on the path visualization for the passengers of autonomous eVTOLs in UAM [17]. However, such research primarily investigates the UX for passengers of autonomous air-taxi applications within UAM.

Although human pilots on board will probably be a requirement (even if just for legal reasons, [4]), there is a lack of research on designing the HMI components for pilots of eVTOLs [18]. To fill that gap, ref. [18] conducted an expert workshop with rotorcraft pilots, identifying them as the closest match currently available to future eVTOL pilots. Apart from basic information (such as altitude, speed, etc.), the research identified the pilots' wish for information in obstacle avoidance, map visualization, and air traffic visualization. A common factor was increasing situational awareness using well-designed symbology.

2.2. Role of Head-Up-Displays and Augmented Reality in Modern Aircraft

With the steady rise in the use of Head-Up-Displays (HUDs) in civil transport aircraft [19], new and modern HMI designs should also consider the benefits and disadvantages of overlaying the outside world with visual information. Focusing mainly on situational awareness, Blundell et al. [20] conducted multiple focus group sessions with experienced airline transport pilot license (ATPL) holders to gain insights on how to design modern Augmented Reality (AR) systems from a user's perspective. This research was not limited to the scope of AAM but general piloting. A key finding was that current HUD configurations just mirror the information already available in Head-Down Instruments. Pilots instead wished for more "context aware" systems. These should be decluttered as much as possible but show relevant information in a condensed way at the right time. Blundell et al. [20] also pointed out the need for UCD-focused research within the domain.

Recent works by Meinhardt, Colley, and colleagues [17,21] specifically also highlight the potential usefulness of AR in AAM. As pointed out above, these works focus on the role of AR in autonomous air-taxi applications in UAM. To our knowledge, the role and design of context-aware displays (such as HUDs and AR) is not yet well understood for human-within-the-loop, SVO-enabled AAM aircraft.

2.3. Roles of Humans, Systems, and Automation in Modern Aircraft HMI

Apart from pure HMI design questions, for true UCD, it is necessary to holistically understand the interaction between the human and the system. Designing with humans in mind should be the general norm, but it is crucial for a completely new control philosophy such as SVO. One proposed benefit of SVO is using automation to reduce training time and requirements for pilot skills [5,22]. Although research warns that increasing automation does not directly translate to a decrease in pilot skill requirements (e.g., [23]), the situation should be seen differently for SVO: here, the automation serves as a shaping factor to the pilot input and does not fully take over the execution of a particular maneuver.

One might argue why such a system is necessary under the decade-long availability of autopilots in aviation. While valid for highly structured flight paths and mission profiles (such as commercial passenger aviation but also for future air-taxi operations between vertiports), several domains exist where the pilot operates more self-directly. One of these domains is HEMS operation. eVTOLs are discussed as options to expand the operational availability of this field [8,9]. Conservative models such as the one by Bruder et al. [9] assume that a dedicated pilot would still be required to operate the aircraft. However, following a concept such as the “40 Hour User” as proposed by Hemm et al. [22] and linking it to the idea of SVO, it should be possible for an emergency doctor or a paramedic to fly to the emergency location themselves. This would maximize the amount of available medical personnel at the location. An emergency doctor and paramedic arriving separately is the usual practice for car-based emergency doctor transfers operating in the rendezvous system.

Based on such a scenario, the information requirements might be related but different from those in the autonomous air-taxi UAM business case like the one in Meinhardt et al. [18]. The research in this work describes the first two steps in the UCD process as defined in [7] for this scenario: understanding and specifying the context of use and identifying the user requirements.

3. Studies

Multiple methods should be used to gain a comprehensive understanding to elicit user and design requirements for a new flight deck concept [24]. The two methods used in this work were the HTA (e.g., [25]) and interviews with subject matter experts (SMEs, [26]).

3.1. Study 1: Hierarchical Task Analysis—HTA

A Hierarchical Task Analysis was performed to understand the sequence of actions and goals in a (generic) HEMS mission with the goal of transferring an emergency doctor from the base station to an emergency location and back. It should also serve as a starting point to understand which parts of a helicopter mission in such a context need to be altered to allow for single-pilot eVTOL operations.

3.1.1. Method

The HTA is a generic human factors method that can be applied in almost all contexts to understand an operator’s tasks to achieve a particular goal [24,25]. As an analytical approach, it can be performed using various materials. The analysis presented in this paper was based on multiple literature sources with descriptions of a HEMS mission in which an emergency dispatcher requests an emergency doctor. To keep the task analysis generic enough to be applied to different locations around the world, sources from multiple countries (Germany, the United States of America, and Austria) were used [9,27–32]. Furthermore, no specific helicopter model was assumed. As mentioned above, previous

results from this purely literature-based HTA were presented in [10]. The modifications for the HTA presented in this paper were based on further refinement of this HTA with a professional HEMS helicopter pilot. This aligns with the recommendations by Stanton [25]. The pilot (age 30) has four years of experience flying as a professional helicopter pilot and logged 300 h of flight with HEMS missions.

For the second step, the helicopter-based HTA from the first step was analyzed further. Actions that are impossible with only a single crew member or require more specific knowledge were modified or omitted. This was necessary to represent the operational constraints of SVO-based eVTOL operations. This step was also already present in Janetzko and Kacem [10]. However, after updating the conventional HEMS mission HTA with the pilot, the eVTOL tasks were also updated to the ones presented in this paper.

3.1.2. Results

The analysis for the first two levels of the HTA is presented in Figure 1. The full HTA with more levels can be found in Table S1 (Supplementary Material). This full HTA also includes the plans and goals for all tasks and describes the sequence in which the (sub)tasks are executed. The HTA describes the steps that must be performed, from checking the helicopter at the beginning of the shift to returning to the station. Key differences between the traditional HEMS mission and the generic SVO-enabled eVTOL mission include the fact that the emergency doctor in the eVTOL must be supported by stronger backend systems (e.g., for weather and mission analysis).

3.1.3. Discussion

The HTA described here can serve multiple different purposes in the UCD process of designing cockpit instruments for eVTOLs in the HEMS context: First, it presents a structured overview of the steps in the HEMS mission profile of transferring an emergency doctor from a base station to an emergency location and back. Second, it analyzes those steps for necessary changes to enable the emergency doctor (or other minimally trained medical personnel) to fly an SVO-capable eVTOL. Lastly, identifying the minimum set of task-related information can prevent future feature creep in HMI design. This problem could occur because a system designer believes a particular display could be helpful but is not actually needed for a specific task. The topic of reduction in the presented information is also further discussed in Section 4.2.

A key difference to the previous version of the HTA presented in Janetzko and Kacem [10] is the sequence position of the preparation of the aircraft, weather, and NOTAM check. In the earlier version, checking the aircraft, weather, and NOTAMs was assumed to be performed before every mission. Instead, the HEMS pilot explained that such preparations are usually only performed at the start of the shift or the day. This changes the time criticality and the depth of information that the pilots can receive dramatically. Current information representations for Meteorological Aerodrome Report (METAR) messages are known to be relatively hard to understand for novice pilots [33]. The same is probably also true for NOTAMs. With the move of the mental preparation for the mission conditions for the day to the start of the shift, the relevant information can be prepared differently and easier to understand for the minimally trained SVO pilots. Graphical representation tools focused on a novice-friendly representation of weather information already exist [34]. Such systems could be used in the briefing phase in the morning or as a way to check the conditions during the day to provide an appropriate level of information for those pilots. This, of course, does not solve the problem of sudden changes in those conditions during a mission. Here, Decision Support Systems (DSSs) must be in place to support the pilot in executing or aborting the mission. The role of these DSSs is also discussed in Section 4.2.

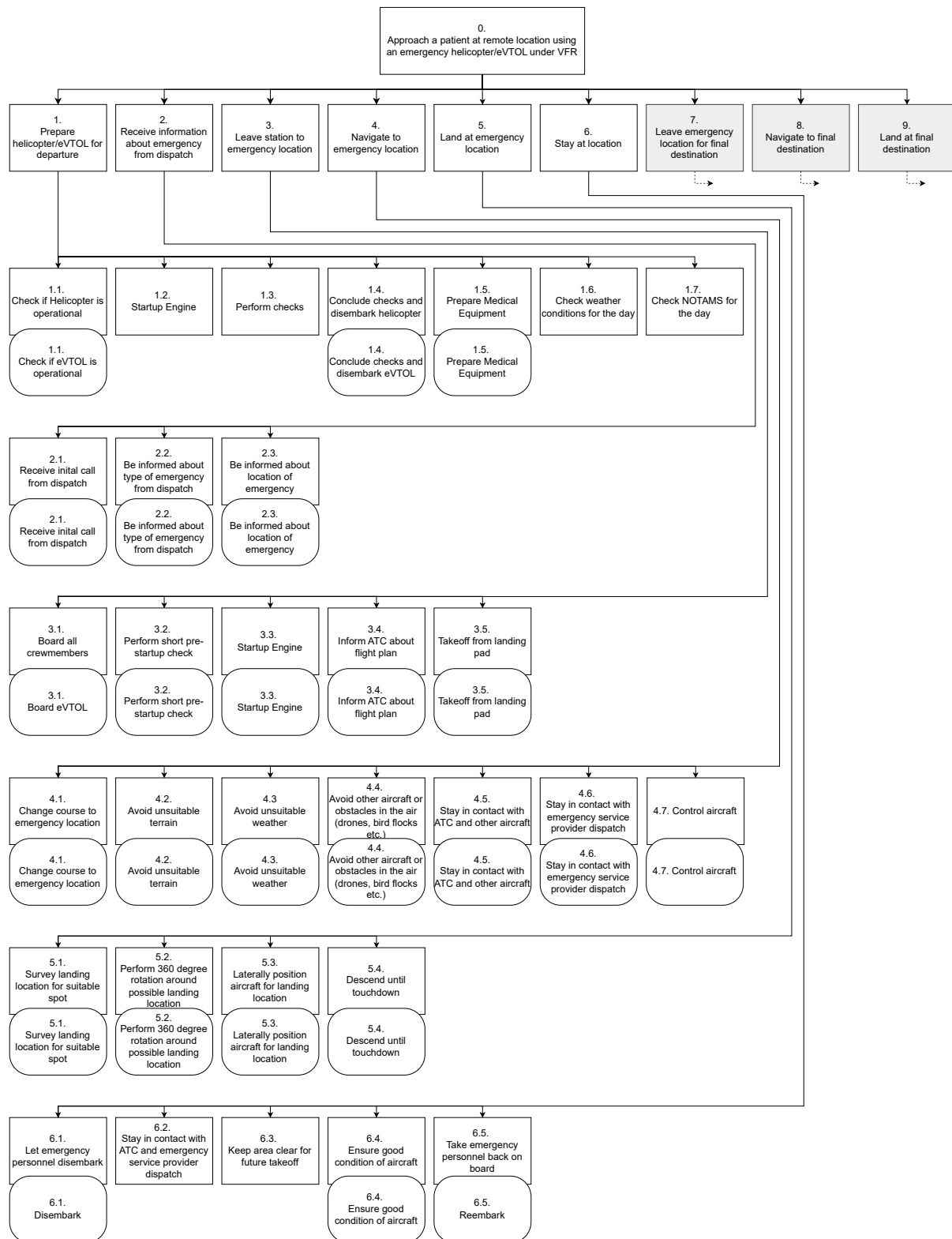


Figure 1. Diagram of the Hierarchical Task Analysis (HTA). Squares with sharp corners show the tasks for a conventional helicopter-based HEMS mission. Squares with round corners show the tasks in an SVO-enabled HEMS eVTOL operated by an emergency doctor as a pilot. Only the first two hierarchy levels of the HTA are shown. For tasks 7, 8, and 9, only the first hierarchy level is shown, as they mostly match tasks 3, 4, and 5.

The HTA for executing the HEMS mission with an eVTOL also accounts for single-pilot operations with no other personnel on board. This represents the most extreme form of onboard crew reduction and goes beyond the concept proposed by Bruder et al. [9] with one dedicated professional eVTOL pilot and an emergency doctor as support. An advantage of a single-pilot operation concept would be an extension of the operational range due to a reduced payload on board the eVTOL. However, under the assumption of a 40-h SVO pilot [22], it is possible to substitute the dedicated eVTOL pilot in the two-person crew with a trained paramedic, maximizing the medical expertise on site. Further factors for this assumption are discussed in Section 4.1.

A limitation of the HTA approach described here is the missing possibility to validate the concept in the real world at the moment. Until certified eVTOL aircraft and their support systems are deployed, the tasks and procedures described in this HTA are analytical and subject to change.

In order to realize this real-world operation, it is necessary to thoroughly understand what information pilots use during the execution of a HEMS mission. Only then can the instruments for future aircraft be designed according to their real-world needs. In Study 2, semi-structured interviews with domain experts from the HEMS sector were conducted to achieve this.

3.2. Study 2: Interviews

The HTA in Study 1 was a purely analytical and literature-based approach. Still, a proper UCD process should also include exchange with (future) system users [26] to understand particularities that are not covered from an analytical approach. This can be described as a “work-as-done” approach [35]. Qualitative expert interviews were conducted to understand which mission, flight, and aircraft information crews use in HEMS scenarios. The interviews aimed to gather first-hand knowledge from SMEs working in the field of HEMS. This approach is comparable to the one by [18] but with a focus on professional HEMS operations.

3.2.1. Sample

In total, $n = 7$ SMEs from professional helicopter mission services were recruited. This is comparable to other studies in the field (e.g., [18]). It also conforms with the finding that information saturation for focused interviews can set in at around six interviews [36] and might be even lower for experts with a high amount of expected consensus [37,38].

Six of the SMEs were professional helicopter pilots with either previous or current experience within HEMS operations. One SME was a mountain rescue service employee who supports the pilots in executing their missions in mountainous areas. All SMEs identified themselves as male. Further information on the SMEs can be found in Table 1. The ethics committee of the Technical University of Munich previously approved the execution of the study.

Table 1. Demographic data of experts.

ID	Age	Experience [Years]	Total Flight Hours	Months since Last Active (HEMS) Mission	Role
1	26	5.5	960	0	Pilot
2	53	22	5100	180	Instructor
3	27	5	80	0	Pilot
4	25	4	900	0	Pilot
5	50	26	7000	0	Pilot
6	20	1	10	0	Pilot
7	27	10	-	2	Mountain Rescue Crew Member

3.2.2. Method

The data were collected through semi-structured qualitative interviews for the pilots and an unstructured interview for the Mountain Rescue Crew Member (SME7). The covered topics were based on a previous selection of pilot skill categories. It was compiled by reducing the pilot skill category list initially produced by the General Aviation Manufacturers Association (GAMA [39]) to the relevant skill list for HEMS operations. The compiled list can be found in Appendix A.

After compiling the skill list, questions were formulated to gather data on how the pilots could be supported in the task execution related to those skills using different HMI components. The pilot of Study 1 was not part of the question generation. No standardized questionnaire was used as the main interest of this study was the collection of qualitative rather than quantitative answers. The SMEs were asked to describe their thoughts and personal experiences on the questions from the following categories:

- General comments and wishes for current HMI components;
- Weather information;
- Navigation information;
- Energy state information;
- Information about the destination;
- Information helpful during take-off;
- Information helpful during landing;
- Airspace information;
- Potential of AR within the mission;
- Comments on current HUD systems;
- Communication exchange between Pilot and Helicopter Emergency Medical Services Technical Crew Members (HEMS TC).

As the interviews were conducted in a semi-structured format, the basic set of questions for each of those categories was the same for all pilots. These can be found in Appendix B. If further clarification was needed to better understand the response for this category, one or two more probing questions based on the response were asked. The interview with the Mountain Rescue Crew Member (SME7) followed an unstructured approach with loose ties to the questions for the pilots, because most of the formulated interview questions were not directly appropriate for such a crew member.

Due to availability reasons, the interview participants were recruited at random at a booth at the “European Rotors” convention in Cologne in November 2022. Participants were only offered the possibility to participate in the interviews if they possessed current or previous experience as professional HEMS flight crew members in Europe. The interviews were conducted in German or English, depending on the participant’s language. Before commencing the interview, the interview partners were briefed on the general goal of the research and its focus on future eVTOL use. Afterward, they signed an informed consent form and started the interview.

3.2.3. Data Analysis

The collected data from the interviews were analyzed following the *inductive, semantic thematic analysis* framework described by Braun and Clarke [40]. The audio transcription and further analysis were performed using the software *Condens* [41]. After transcription, one of the authors performed coding for the whole data set. The coded snippets were placed on a digital whiteboard to form thematic clusters. These clusters were further refined and named to produce the themes reported below.

3.2.4. Results

Three main themes were identified in the analysis: **Early Knowledge, Tasks During the Flight**, and **Information Processing**. For direct quotes from the SMEs, a (G) denotes

that the original answer was given in German and was translated by one of the authors for reporting.

Early Knowledge

This theme combines topics where the SMEs indicated that an early information flow helps them mentally prepare for the flight in general or emergencies. Within this theme, four subthemes were identified: Take-Off and Preflight Management, Power Management, Safety First Mindset, and Aircraft Calculations.

Take-Off and Preflight Management The SMEs explained that it is crucial for them to (at least briefly) check that they and their aircraft are ready to fly. If other crew members are on the flight (the norm for HEMS operations), a short preflight briefing and information exchange on the mission is conducted. Such a briefing and check also includes checking the weather conditions for the flight. The SMEs highlighted the importance of such a (mental) preparation for the flight to ensure a safe execution.

Power Management The SMEs also wanted to be informed early about (potential) problems with the available power of their aircraft. Two aspects were mentioned in this regard: Early information if the current destination is not reachable (e.g., due to temperature and altitude) or if the current power setting poses a problem for the aircraft (i.e., is close or even above the power limit). The SMEs mentioned that they are constantly checking engine parameters in relation to their current operation. Being able to tell early if a problem can or will occur would help them. Especially in HEMS operations, this often relates to weight aspects and current weather conditions (e.g., loading on a passenger at a high altitude might prevent the helicopter from taking off).

Safety First Mindset Basically all of the decisions by the SMEs follow a “Safety First” mindset. This means that in case of doubt about the safety of an operation, the abortion or non-acceptance of a mission request is always an option. In this subtheme, the SMEs talked about the importance of their knowledge about the energy state of their aircraft. Therefore, they wanted to quickly know whether their destination is still reachable. For this, a warning cascade (with previous caution stages) and notifications about abnormal trends in their energy draw were mentioned several times. Within this subtheme, multiple SMEs also talked about psychological aspects that can play a role in executing HEMS missions. [SME2 (G)] mentioned “that everyone wants to finish what they have started” and the need to balance this with the safety-first mindset (“*this [aborting or continuing a mission] is not an easy decision*”). [SME5] explained that in HEMS operations, too much knowledge about the medical aspects of a mission (e.g., when a child is involved) could lead to unsafe behavior: “*There is a three-year-old baby that needs urgently to get to the airport, which is sad, but you do not want to kill another five people just because it's so*”.

Aircraft Calculations Multiple SMEs talked about the helpfulness of automatic aircraft calculations. Specifically, the aspect of power management based on current conditions (weight, temperature, altitude, etc.) was pointed out. In general, systems that integrate multiple information sources (such as energy status, weather, distance, etc.) and support decision processes were seen as beneficial. The SMEs generally appreciated the idea that the aircraft presents multiple options (e.g., alternate landing spots) based on such calculations but leaves the final decision to the pilot. In contrast, it was also mentioned several times that pilots gain experience on the specifics of their aircraft and calculate or guesstimate aspects such as remaining flight time based on the energy draw and power settings. Nevertheless, systems that support this process would still be seen as helpful to reduce the mental workload.

Tasks during the Flight

This theme collects the different tasks that need to be performed and aspects that play a role during the flight. Five subthemes are contained within this theme: Collision Avoidance, Approach and Landing, Crew Interaction, Navigation, and External Information.

Collision Avoidance This subtheme revolves around the multiple aspects of collision avoidance that the pilots have to perform during the flight. These can be static obstacles (such as buildings or the terrain) or dynamic obstacles (such as other air traffic). One key focus for this theme was flight at low altitudes (as this is a crucial part of HEMS operations). Major static obstacles mentioned by the SMEs were power lines, cables (e.g., from cable cars), and wind turbines. The avoidance of such obstacles plays a significant role in the safe operation of the helicopter, and any system that supports the pilots in this task was welcomed. Automatic detection and highlighting of obstacles that are not very well visible (for example, using LIDAR) were mentioned several times. [SME 4 (G)] also specifically highlighted the wish that obstacles were visually clearly separated by different icons or colors depending on the type of obstacle. This is because *“if it is a powerline, it could be over a whole area. Or if it is only wind power [turbine], then it is only at one point and I can fly around it”*. Such issues with obstacles play an even more important role during take-off and landing, where the margin for error is slim, and the helicopter naturally operates closer to the ground. Regarding dynamic obstacles, a clear highlighting of crossing traffic was wished for. This should be based on live tracking and automatic detection by the aircraft. Some SMEs also wished for a display of the radio frequencies for the aircraft and airfields in the area to contact them quickly. Other SMEs (e.g., [SME 4 (G)]) did not see the necessity for such a tool as *“it is already mandated that [...] if you are close to an airfield, one should be on the same frequency as the airfield anyways”*.

Approach and Landing For the topic of Approach and Landing, two cases were differentiated by the SMEs: the approach and flying to the designated landing spot and alternate or fast landings in case of an emergency. For the first case, if time permits, a quick check of the planned destination via satellite pictures is performed. This also entails a mental preplanning on the possible approach direction. Furthermore, the weather at the destination plays a crucial role, and the pilots try to estimate the conditions as early as possible. Therefore, a camera feed from the destination would be a wish (albeit recognized as probably unrealistic by most experts). In case of alternate landings, the SMEs wanted to stay informed about possible landing locations for their current route. For both types of landing, the SMEs stressed the importance of the surface conditions at the landing spot (which in HEMS operations is often not a paved heliport). This regards a possible terrain slope but also the density of the ground and dust conditions due to the weather. As an intersection between the topic of landing and collision avoidance in this theme, the helpfulness of cameras at sensible locations was mentioned multiple times.

Crew Interaction As in current HEMS missions, a multi-person crew is involved, the SMEs talked about the pilot's interaction with the rest of the crew (mainly the HEMS TC). In this aspect, the SMEs mainly believed that a second (or third) crew member is generally beneficial. However, they also pointed out that a safe helicopter operation must be possible without multiple crew members. As mentioned above, from a psychological standpoint, it can also be a safety hazard if the pilot is too involved in the patient's medical status. Therefore, the crew interaction on this topic is usually reduced. The role of the HEMS TC (if trained appropriately) was seen as very positive as they can support the pilot, for example, with radio communications. Furthermore, due to their knowledge of the aircraft's behavior, they are helpful in assessing the available weight and power conditions.

Navigation Within this subtheme, most SMEs were satisfied with current navigation displays. The availability of moving maps (essentially replacing analog printed maps in everyday operations) was seen as positive. A simple display with a line between different waypoints or to the final destination was preferred. Some SMEs would only add the heading to the moving map as well. Several SMEs specifically mentioned the integration of the navigational displays from the manufacturer Garmin as positive. Some SMEs talked about the relationship between the navigation in the terrain and required altitudes. Regarding early planning or warning, these experts would then like to be notified that their aircraft does not have the climb power for an upcoming part of the route.

External Information One shortcoming at the intersection between collision avoidance and navigational displays is the problem of outdated external information. In this regard, wind turbines were explicitly mentioned: a map might show just a few of them in a particular area, but in the meantime, multiple more were or are being built. Here, the SMEs sometimes went for the workaround of collecting the information on such obstacles in a self-updated obstacle database for their Electronic Flight Bag (EFB). In areas they know well (usually around their home base), this problem is not so pervasive, or the obstacles are even used as visual navigational aids. Nevertheless, the SMEs were displeased that they can only partially trust the external map data. Therefore, the idea of synthetic vision and automatic obstacle detection in the aircraft was seen as very positive.

Information Processing

This theme collects general aspects of information display and interaction with it. Three subthemes comprise this theme: Operational Factors, Information Overload, and the View to the Outside.

Operational Factors Within this subtheme, the SMEs talked about the fact that information requirements and display depend on the flight rules the helicopter operates under, which flight phase they are in, and the possibility of changing conditions. Concerning the flight rules, the SMEs highlighted the fact that some instruments (e.g., the Primary Flight Display, PFD, and artificial horizon) only play a role under Instrument Flight Rules (IFR), while they are unnecessary under Visual Flight Rules (VFR). Regarding different information needs for the flight phase, the SMEs highlighted that especially the take-off requires different information (mostly power-related) than the other flight phases, such as cruise and landing. One crucial aspect concerning various topics was the possibility of changing conditions. A key aspect within this subtheme were the (changing) weather and wind conditions. Changes in the mission requirements and emergencies were also mentioned here.

Information Overload One of the core topics mentioned by almost all SMEs was the importance of condensing information and avoiding information overload. For most of the discussed information displays, the consensus can be described as “less is more”. Pilots need to integrate much information from different sources and were therefore always interested in getting the relevant information as fast as possible. In the eyes of the SMEs, this often meant that related information should not be scattered over too many instruments but rather grouped. One way of achieving this is by clustering the information on grouped information tabs. There were mixed opinions on whether such tabs should be grouped by system or flight phase. In such a system, manual switching of these tabs was generally preferred. As part of such a clustering, the SMEs also wished for the possibility to adapt the displayed information based on personal preferences. Generally, the experts preferred an information display directly related to their further information processing. As an example, the energy display was mentioned: here, the remaining energy level should not be displayed in an abstract percentage but rather in the remaining flight time or range. However, the SMEs once more highlighted the importance of this information being accurate, reliable, and as stable as possible. The possibility of the latter was questioned due to changing operational factors.

View to the Outside While talking about the relevance of specific instruments, one general reappearing theme was the importance of looking outside when operating under VFR. The SMEs described that a lot of information regarding the altitude and speed of the aircraft and distance to other aircraft is monitored by looking outside. Therefore, systems such as AR glasses or HUDs were seen as beneficial as they reduce the need to look at the head-down instruments. However, especially for such displays, the need for effective decluttering and an option for personal adaptation was highlighted.

3.2.5. Discussion

Study 2 in this paper represents in-depth expert interviews with seven SMEs from the HEMS sector. The rationale behind these interviews was the collection of data on the “work-as-done” [35] aspect of HEMS missions. The SMEs were asked which information and information representation they rely upon when executing their missions. The approach is comparable to the study by Meinhardt et al. [18]. In general, the results show a substantial overlap, indicating the validity of the approach and the conclusions drawn from it. Before looking at specific new information for the HEMS scenario, a short overview of factors appearing in the data from [18] and the current work shall be given.

Common Findings with Meinhardt et al.

The SMEs in both studies reported that collision avoidance is a significant factor for every phase of the flight. However, the type of obstacles and dangers differ between the different flight phases: during take-off and landing, static obstacles in hard-to-see areas of the helicopter pose a high risk for the aircraft. For faster forward flight, obstacles that are hard to see from a distance are emphasized. These can be, for example, power lines and cables in mountainous areas. As an intersection between the themes of *Early Knowledge* and *Collision Avoidance*, the SMEs want to prepare as early as possible when flying to a particular area. When the documentation on the obstacles is outdated, this poses a significant psychological burden on them.

Such early knowledge about the relationship between the aircraft and the environment was also mentioned in other themes in both studies. This concerns the knowledge about other traffic in the area, weather fronts, and prohibited airspace. The SMEs highlight the importance of high situational awareness for these factors [18].

Another common finding between both data sets is that the information needed for missions can change depending on various factors. In the data reported in this paper, in particular, the differences between IFR and VFR flights were mentioned multiple times. As a general finding, the SMEs prefer to look outside as much as possible. Therefore, under VFR, the PFD (if available in the aircraft) does not play an important role in evaluating the attitude, altitude, and sometimes even the aircraft’s speed.

In contrast to the work by Meinhardt et al. [18], the interviews described here focused on the mission profile of HEMS operations. The SMEs in [18] also describe that the conditions and information requirements can drastically differ under such a purpose. Here, it becomes clear that missions are performed under more time pressure, and changing conditions appear frequently. The following section shall describe in more detail the consequences of this.

Specific Findings for HEMS Operations

In contrast to wide-body, commercial aviation, or passenger transfer under good conditions, HEMS missions are performed under more dynamic and challenging conditions. Examples of this are the need to land outside designated airfields, operate close to the ground, or in areas with problematic terrain. As mentioned above, this can also involve flying in non-optimal weather or visual conditions. Due to the need for constant evaluation of various mission parameters (distance, energy state, power factors, etc.), the SMEs described a need for condensation and clustering of information. For example, [SME2] and [SME5] described that they prefer to have a quick glance in the instruments to see whether “everything is green”. Apart from HEMS operations, this is not a new finding for aviation displays [42]. However, for HEMS, the importance of this finding is increased due to the more dynamic environment described above. From an information architecture point of view, HMI designers should, therefore, critically ask themselves if all available information must be presented at all times or if it is possible to combine the status of multiple systems into one or fewer displays. One positive example mentioned by the SMEs was the First Limit Indicator (FLI), which is, for example, used in the EC-135. This single display quickly informs the pilot if their aircraft operates within system limits of

the Engine Torque, Turbine Outlet Temperature, and Compressor Speed [43]. Integrating multiple information sources can follow the analysis automation framework described by Parasuraman et al. [44]. Supporting the pilots with such clear indications that integrate multiple information sources should be beneficial for their mental workload [45].

One way of information reduction suggested by the SMEs was the request for personal adaptability of the displayed information. Multiple SMEs indicated that their information needs differ throughout the flight but might also differ from pilot to pilot. While key performance parameters like the engine and power parameters mentioned above played a role for all of them, certain additional information was only relevant for certain flight phases or if pilots specifically requested it. One example of this was the display of other air traffic in the area: while the SMEs generally wanted to be aware of the traffic around them, a continuous display of all traffic was declined explicitly by some of the SMEs. Instead, they wanted to be informed if there is crossing traffic that might interfere with them or specifically toggle the display of other traffic. All of these findings point back to reducing the general amount of information but making it available on request. Future HMI designers should, therefore, critically examine if a specific indicator must be displayed continuously or could be made available on request. As an extension, personal presets for such an HMI should also be examined to avoid the need to rearrange the displays at the start of a flight.

As pointed out above, HEMS crews often operate closer to such system limits than “routine” private or leisure pilots. While technical limits (like the FLI) exist for some of them, the pilot must evaluate other operation conditions based on multiple sources. For example, the SMEs must often balance the aircraft’s energy state (and effective range) with the time criticality, wind conditions, and weather. These evaluations often also include the option of canceling a mission. The SMEs report that these evaluations also bring significant psychological consequences: [SME2] mentioned that crews might have the urge to finish a started mission. [SME3] and [SME5] point out that too much knowledge about the patient’s state or the mental hurdle of unloading a patient due to weight problems could lead to unsafe behavior. Therefore, balancing these psychological effects with a safety-first mindset is difficult but must be a high priority in HEMS operations. A key design aspect for SVO-enabled HEMS eVTOLs must, therefore, also be a robust DSS that evaluates the state of the aircraft and outside conditions. Further details on the consequences of DSSs are discussed in Section 4.2. To avoid these psychological pitfalls, the safety limits in such a DSS must be larger than in “professionally” flown aircraft.

On top of the above findings, the SMEs stressed that a lot of external information on static obstacles is outdated. This is not only a problem for HEMS operations but helicopter operations in general. However, as pointed out above, this problem is more severe in HEMS operations, as pilots need to operate in areas that would be off-limits for private aviation. Multiple SMEs, therefore, wished for scanning systems built into their aircraft. Such systems can be seen as a form of synthetic vision. In such a system, virtual or augmented images enhance the view to the outside. Lombaerts et al. [5] recommend synthetic vision for SVO in general.

As can be seen from these results, SVO-enabled HEMS operations would need to consider more factors than private or passenger UAM operations. To complete this in a user-centered way, the results from both studies in this paper are synthesized in the next step. Afterward, guidelines on the type and visualization of the information for such operations are deduced.

4. General Discussion

Two qualitative methods were used to gather the (future) user and task requirements for the performance of HEMS operations. First, a HTA of a conventional HEMS mission and its transference to an eVTOL [10] were modified with a HEMS helicopter pilot. In the second step, seven SMEs from the HEMS domain were interviewed. These interviews aimed to collect information on the work-as-done [35] perspective in the HEMS domain.

Together, these methods can be used to design HMI components for future aircraft in this domain.

4.1. Relationship between HTA and SME Interviews

The reasoning behind presenting the HTA and the pilot interviews together in this work is based on the goal of designing future avionic displays from a task and user perspective rather than an engineering perspective [46]. The scenario for the HEMS operations in this work is based on the medical emergency system operating under the “rendezvous concept” [47]. In this system, the non-transporting EMS vehicle is not being used to transfer the patient back to the hospital but only to get the emergency doctor to the emergency location as fast as possible. After the initial care at the emergency location is finished, the emergency doctor then either returns to their base station, follows the transporting EMS vehicle to the hospital, or joins the crew of the transporting EMS vehicle on their way to the hospital. To allow for the latter case, many non-transporting EMS vehicles in car-based rendezvous concepts are driven by another paramedic who follows the emergency transport vehicle. It is true that with a strict SPO assumption (as carried out in the HTA), such mission profiles would not be possible. However, as described by Rössler and Zuzan [47], the significant benefit of the rendezvous concept is the reduced dispatching time to get the doctor to the emergency location as fast as possible. Bruder et al. [9] also describe eVTOLs as an addition to the resource pool in the Emergency Medical Service (EMS) space and not as a substitution. As a future extension that fully incorporates strong SVO, a two-seater eVTOL with a paramedic as a pilot would be possible. This would maximize the available medical personnel on-site and would still allow the emergency doctor to join the patient transfer.

The analysis of the HTA and the data in this paper, as well as [18] highlight that information needs can change during a flight depending on the flight phase and the current task. Schvaneveldt et al. [48] performed multiple analyses to assess the relative importance of information clusters for conventional civil aviation. They also relate one of their analyses to that of a task analysis but do not label it as a strict one. Instead, they also aimed to identify overarching task sequences that can be generalized to the task of flying conventional aircraft. They found considerable differences between different phases of flight (e.g., the available power being of higher importance during take-off than landing). Although their findings can not be directly applied to the scenario underlying this paper because it focused on fixed-wing aircraft and civil transport aviation, the SMEs in our interviews reported relatable changes of information importance. The aspects that were directly reported by the SMEs in that regard are as follows:

- Power availability is important during the take-off phase due to environmental and altitude conditions;
- Available range or flight time is constantly monitored, especially during the cruise flight (not so much during the take-off or landing);
- Aircraft configuration does not change substantially for landing (which is different from fixed-wing airplanes).

Based on their findings, Schvaneveldt et al. [48] also proposed a critical reflection on current instrument designs to make them more task-oriented.

One study that applied such an approach in the display of information HUDs was performed by Richards et al. [46]. In their study, multiple HUD configurations were tested for their effectiveness in improving the flight performance during an approach and landing task. The critical analysis focused on comparing a “full” HUD configuration and one that only shows information relevant to the current task of landing the aircraft. From a performance perspective, the task-focused HUD did not bring a measurable difference, but the reported workload of the pilots was reduced under the task-based condition. In our eyes, the role of such reduced, task-based displays should be revisited for SVO-based eVTOL operation. In such conditions, flight phase-dependent information displays could have a significant advantage: the control scheme of the aircraft can change dramatically

while maintaining an intuitive approach [49–51]. For such a concept, staying with the same information representation for the entire mission could lead to mode confusion, endangering the pilot and the aircraft.

Based on both analyses, there are key learning points on the importance of specific information clusters that need to find an appropriate place in a task-oriented HMI design for SVO eVTOLs in HEMS operations. These clusters are described in the next section, followed by deduced guidelines for representing this information.

4.2. Information Needs and Tasks for Flying an SVO-Enabled eVTOL in HEMS

Based on the fact that the SMEs reported that they would wish for more support in analyzing the amount of data available, it is safe to assume that the same would be true for minimally trained SVO pilots. Even more so, with the proposed reduced training times for SVO pilots, more assistance is needed. For such assistance, the potential of DSSs could be leveraged [44].

For SVO in the HEMS context, the levels of *Analysis Automation* and *Decision Automation* according to Parasuraman et al. [44] would be appropriate. One example that was described by the SMEs was the automatic highlighting (and suggestion) of possible emergency landing spots based on the current route, aircraft, weather, etc. Although task performance with the use of DSS has been shown to increase (e.g., [52]), from a human factors perspective, automated DSS come at a cost. Most prominently, automation bias must be considered here [53]. Therefore, future HMIs of SVO eVTOLs must be fine-tuned to find the right balance to avoid over-reliance while enabling minimally-trained pilots to operate the aircraft safely.

Referring to automated data analysis, the SMEs described the importance of good power management in the HEMS context. As this is a complex interplay between the aircraft, weight, weather conditions, altitude, etc., minimally trained SVO pilots might lack the knowledge and skills to safely and adequately evaluate the available aircraft performance. Therefore, we suggest a strong integration of assistance systems for power management in SVO-enabled aircraft. Systems like the FLI already provide a good starting point, but integrating a more holistic perspective seems warranted in the HEMS context.

Although not at the core of this paper, the topic of training must be touched on based on those arguments. Due to the variety of eVTOL characteristics [1], the training of future pilots must reflect the knowledge of the limits of such automation systems. In order to still benefit from the proposed reduction in training time for SVO [5], the training should focus on handling one specific aircraft (i.e., a type-rating) rather than a general ability to fly. Depending on the capabilities of the aircraft and the available DSSs, the inclusion of general aviation training topics (such as meteorology, radio data links, etc.) must be decided on an aircraft-by-aircraft basis. Within such aircraft-specific training, the SVO pilots must also be prepared to deal with failures of the nominal control law in their aircraft. Modern aircraft using Fly-by-Wire (FBW) controllers (such as the Airbus A320 or A340 but also proposed SVO-based aircraft) include backup or degraded control laws [6,50]. These ensure that even with automation failures, the aircraft can still be controlled. Nevertheless, due to the change in response behavior, such cases should still be part of the aircraft-specific training.

Based on the reports from the interviews and the results from [18], collision avoidance is one of the most safety-critical but ubiquitous tasks in helicopter operations. However, the types of obstacles to avoid differ for the different flight phases (see Common Findings with Meinhardt et al. in Section 3.2.5). To incorporate the operational reality of HEMS operations in the HMI of eVTOL, we support the suggestion of Lombaerts et al. [5] to make synthetic vision a high priority for SVO. The range and resolution of the collision warning must match faster forward flight as well as low-speed hovering.

4.3. Guidelines for Information Design

Based on the synthesis of the findings in this study but also from other research, the following guidelines for the design of the representation of this information can be formulated.

4.3.1. Highlight System Limits

As described above, HEMS aircraft operate closer to technical system and operational limits than private helicopter aviation. For SVO, the minimally-trained pilots might not be trained as well as current professional HEMS pilots to evaluate such limits and, therefore, need more guidance on understanding what they can and cannot do in the current mission. Therefore, the instruments for such a system should clearly indicate what boundaries to their mission execution are currently in place. Such limits include maximum altitudes, maximum airspeeds, weight factors, etc. One particular case of such limits is the range. The SMEs described regularly reevaluating if a destination is still within their effective range and flight time. As emergency locations in HEMS missions usually do not provide the possibility to refuel (or, in the case of eVTOLs, recharge) an aircraft, calculating and displaying the effective range must also consider the return path. Higher safety margins must be in place for SVO aircraft so that unsafe situations are avoided but also so that substitute emergency crews can be dispatched to the scene early enough.

4.3.2. Analyze Abnormal or Problematic Trends

The interviews made it clear that the SMEs also use abnormal trends in their aircraft data to identify potential (future) problems. Such trends, for example, appear in abnormal fuel draw or less-than-expected climb performance. This requires substantial knowledge and experience with a specific aircraft and its behavior over time. While using such trend data provides a strong safety barrier before a minor issue becomes a more substantial problem, such experience can not be expected from the minimally trained SVO pilots. Instead, comparable to the system limits in the previous point, the aircraft should analyze abnormal trends automatically and communicate that something is not correct.

4.3.3. Make Status Easily Scannable

Pilots in the HEMS context have to deal with multi-task loads. Especially during take-off and landing, collision avoidance and power management must be performed with the utmost care. To learn from the positive example of conventional aircraft, it must be easy for the pilots to scan the aircraft for nominal as well as non-nominal conditions. It should, therefore, be the standard to reduce the amount of information in nominal conditions to keep the information clutter as low as possible. Condensed information that there are no problems to report as a system status page is preferable in this case.

4.3.4. Translate Aircraft Status into Actionable Information

To keep in line with the task-based information representation instead of the engineering perspective, aircraft and mission status representation should be translated into actionable information. This means that the HMI should inform and assist the SVO pilot in dealing with a specific status instead of presenting it without context. One example of this is the display of the energy state of the aircraft regarding the range: multiple SMEs stated that, for them, the range in miles or remaining flight time in minutes is much more informative than a pure percentage display. In case of an emergency, clear actions to be performed should be formulated to deal with the error. This is comparable to the Electronic Centralized Aircraft Monitoring (ECAM) caution and warning display in Airbus aircraft. These provide clear action lines on how to deal with identified technical problems.

4.4. Limitations

As mentioned above, the most significant limitation of the studies in this work is the need for more possibilities for validating the conclusions in the real world: there are no certified, commercially used eVTOLs in the market for any use case. Therefore, they are also not yet used in EMS operations. The direct “translation” of tasks from the helicopter EMS operations may not be applicable for eVTOL EMS operations. This is due to the different technical configurations of the aircraft but also due to a possible change in operation type. For example, the scenario described in this work was specifically chosen to

be executable using a one-seater eVTOL. However, it does not represent another prevalent HEMS operation type in which the patient is transported back to the hospital via helicopter. Nevertheless, making certain assumptions is necessary to take steps toward designing a valid system.

We understand the potential criticism of relying on a single coder for the thematic analysis. This was a conscious decision based on current guidelines by Braun and Clarke [38] for a thematic analysis. These specifically require only a single coder as long as the focus lies on an in-depth understanding of the themes instead of consensus between coders. We are aware of the subjective nature under which codes and themes are generated but see this as an integral part of thematic analysis. Constant reevaluation of the used codes and how they relate to the full data set ensures that the final codes and themes are fundamentally stable and representative of the data [38,40]. Early coding was also performed in light of existing research in the field such as the one by Meinhardt et al. [18].

Although debatable, the decision to look at the scenario and aircraft generically was deliberate. We believe that this is appropriate for the current state of the research in the domain. It allows for the incorporation of future changes in the actual implementation of the operation. It also avoids focusing too much on the technical feasibility side of design solutions. This would limit the solution space too early, while the work described here is focused on a structured problem definition for which solutions must be developed.

4.5. Future Research

As described by Parnell et al. [24] and in ISO 9241-210 [7], understanding the requirements of users and their tasks in a structured way is the first step in the UCD process. Therefore, the next logical step is the development of design solutions that support users in the described scenarios. Such solutions must also incorporate findings that are not specific to this HEMS scenario but also general findings in the field of modern aircraft HMI design (e.g., [18,20]). A specific focus in the SVO space must be finding an appropriate information design for non-aviation professionals. As Wright and O'Hare [54] could show, flight-naïve users believed they would perform better with modern tape-displays for altitude and speed but performed worse. Therefore, a newly designed HMI for SVO eVTOLs must be reviewed even more critically than the redesign of instruments for conventional aircraft. One way of performing such an analysis analytically while including the available HTA is the execution of a tabular task analysis (TTA, [55]). In this analysis format, the information on the tasks is enhanced with further details like the available information, feedback from the system, or possible errors in the execution of the task.

5. Conclusions

Two qualitative methods (an HTA and interviews with SMEs) were conducted to understand the tasks and display requirements in executing a HEMS mission. The data were then interpreted in light of the potential future use of eVTOLs as an addition for airborne EMS. It now serves as a guideline for future HMI design solutions. These display components should support the pilots of eVTOLs in EMS missions, primarily based on current tasks and flight phases.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/aerospace11030197/s1> Table S1: Hierarchical Task Analysis for a Helicopter/eVTOL Emergency Medical Service Mission.

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Abbreviations

The following abbreviations are used in this manuscript:

AAM	Advanced Air Mobility
AR	Augmented Reality
ATC	Air Traffic Control
ATPL	Airline Transport Pilot License
DSS	Decision Support Systems
EFB	Electronic Flight Bag
FBW	Fly-by-Wire
FLI	First Limit Indicator
ECAM	Electronic Centralized Aircraft Monitoring
EMS	Emergency Medical Service
eVTOL	electric Vertical Take-Off and Landing system
GAMA	General Aviation Manufacturers Association
HEMS	Helicopter Emergency Medical Service
HEMS TC	Helicopter Emergency Medical Services Technical Crew Member
HMI	Human–Machine Interface
HTA	Hierarchical Task Analysis
HUD	Head-Up Display
IFR	Instrument Flight Rules
METAR	Meteorological Aerodrome Report
NGO	Non-Governmental Organization
NOTAM	Notice To Air Mission
PAV	Personal Aerial Vehicles
PFD	Primary Flight Display
SME	Subject Matter Expert
SVO	Simplified Vehicle Operations
UAM	Urban Air Mobility
UCD	User-Centered Design
UX	User Experience
VFR	Visual Flight Rules

Appendix A. Relevant Skills from GAMA

The following list shows the skills identified as relevant to the scope of the interviews in this paper. It was compiled by reducing the skill list provided in [39] to the skills appropriate for nominal SVO HEMS operations.

- Aircraft Handling;
- Communication;
- Detect and Avoid;
- Navigation;
- Planning;
- Risk Management/Decision Making;
- Systems Management;
- Take-Offs and Landing.

Appendix B. Interview Questions for HEMS Pilots in Study 2

The list of questions for the semi-structured interview with the pilots in Study 2. The questions are presented in English for this paper. If the interview was conducted in German, direct German translations of those questions were used.

- General Questions
 - Which HMI components provide the most information you need for your mission?
 - Which HMI component do you need the least?
 - Which component do you wish you had, but have never had before?
- Weather
 - How is weather information displayed nowadays?
 - How would you like the weather information to be displayed?
 - An automated tool would retrieve the weather information itself, analyze, it and make the decision for GO/ NO GO and display it: What do you think about this system? How would you like the information to be displayed?
- Navigation
 - How would you like the flight path to be displayed?
 - What are the challenges you face during low-altitude flight?
 - What information are you missing?
 - What information could help you better control your aircraft?
- Energy
 - If you have a critical battery capacity left on board during flight, how would you like this information to be displayed?
 - How would you like to have the energy consumption of your aircraft displayed during flight?
 - Would you check yourself if the amount of energy remaining matches your calculations before take-off and is enough to reach the destination?
- Destination
 - What would you like to know about the place you are flying to? How would you like this information to be displayed?
 - What do you think about a display with a digital map (similar to Google Maps) that shows not only the route but also all other external influencing factors (e.g., possible problems related to different wind directions or obstacles)?
 - What information about the surroundings are you missing in a busy airspace or with limited visibility? In what form and where should it be displayed?
 - In case of low battery level, what do you think about a tool that automatically calculates the distance and time to a reachable destination, as well as the amount of energy needed for that?
- Take-Off
 - What information should be presented to you before/when you take off?
 - How would you like to receive this information?
 - What do you think of a tab in a display that summarizes all the information needed to take off in one place?

- Landing
 - What information do you need before landing?
 - How do you monitor the sink rate, power margin, and speed?
 - What do you think of a system that monitors these values and orders a go around if they are exceeded?
 - What do you think of a tab in a display that summarizes all the information needed to land in one place?
- Airspace
 - How would you like information about possible oncoming traffic to be displayed?
 - How would you like to receive information about dangerous and prohibited areas as well as traffic?
- AR Glasses
 - AR refers to the interaction of digital and analog life. This could work, for example, via a pair of glasses. The user is not completely cut off from their normal environment. Rather, additional information about their surroundings is superimposed on the glasses. What do you think of AR glasses in executing your operation?
 - What information would you like to see displayed via AR glasses?
 - Do you want this information to be selectable or displayed all of the time?
- HUD
 - What do you think of the head-up display during the operation?
 - Which information would you like to be shown by the head-up display?
 - Do you want this information to be selectable or displayed all of the time?
- Communication Pilot - HEMS
 - What information do you need from the HEMS TC when performing your mission?
 - Could this information be provided by HMI and thus replace the HEMS TC (e.g., display)?

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