APPLICATION OF A HIERARCHICAL TASK ANALYSIS IN THE DESIGN PROCESS OF AN EMERGENCY EVTOL HMI

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Abstract

Urban Air Mobility (UAM) and the concept of electric Vertical Take-Off and Landing (eVTOL) systems are on the way of becoming reality. Closely related, the concept of Simplified Vehicle Operations (SVO) is often discussed as a way of reducing the training required to operate those aircrafts.

Currently discussed display configurations of eVTOLs are usually based upon traditional display concepts. However, following the User Centered Design (UCD) and the SVO approach, it is preferable to redesign such display configurations with (future) users in mind. Consequently, it is necessary, to reevaluate the amount and way that information on the current aircraft status is communicated to the pilot.

A Hierarchical Task Analysis (HTA) was conducted to identify a design space for this change in design philosophy in the UAM context. The HTA was based on a generic emergency helicopter mission, in which an emergency doctor has to be transferred to a patient in a remote area. In a second step, the tasks from the HTA were analyzed for necessary adaptions for a future single-pilot operation in the emergency mission context. First guidelines for adaptations are derived.

Keywords

Urban Air Mobility; Human Factors; Human Machine Interface; Task Analysis; Simplified Vehicle Operations

1. INTRODUCTION

The field of Urban Air Mobility (UAM) is projected to be a growing field in aviation for the coming years, steadily increasing the number of passengers and routes [1]. Although discussions on novel approaches in technical feasibility of the different electric Vertical Takeoff and Landing (eVTOL) concepts already make their way into the legislative process, aspects on the display configuration usually rely on existing guidelines [2]. However, with the possible advent of Simplified Vehicle Operations (SVO) as a more automated flight control system in eVTOLs, the need for a redesign of the Human Machine Interface (HMI) for those systems becomes apparent [3]. Apart from the potential as a novel passenger transport system, eVTOL systems have also been discussed as a tool for the domain of air ambulance services [4]. If the concept of SVO allows for a significant reduction in complexity and training for the control of an eVTOL, one possible use case could be the “self-transfer” of an emergency doctor to a patient in a remote location. To understand, which adaptations to the HMI would be necessary to allow for such a mission profile, it is necessary to explore which tasks and tool play a major role in such a scenario.

2. THEORETICAL BACKGROUND

With growing interest in eVTOLs as a mode of passenger transport, first projects and feasibility studies for the use in the context of air ambulance services are also arriving [4, 5]. For example, multiple Monte Carlo analyses under different eVTOL configurations were performed, to understand the time budget and technical requirements for those aircraft if used in an air ambulance service scenario [4]. To understand whether such a service could be implemented in the German emergency service system, a multi-stakeholder analysis from different perspectives (technical, ecological, economical etc.) was performed [5]. Both studies come to the conclusion, that eVTOLs could fill such a role in an emergency service system but also point out that major challenges need to be solved in order to be successful.

One of these challenges is the probably required reduction in crew size to increase the range of the aircraft and lower operational costs. One possibility in the domain of aeromedical services could be the substitution of the aircraft pilot with a medical crew member. Projects like mycopter [6] have shown that the complex task of controlling an rotor aircraft can be made accessible to “the general public” through changes in the HMI.

Research in this area is also part of the growing field of SVO [3]. In this concept, an increasing amount of automation and reduction in the complexity of the “low-level” control of an aircraft allows for a reduction in pilot

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training. [7] for example propose the concept of a "40 Hour User" who would have received approximately 40 hours of training and 60 hours of practice on the aircraft. One could imagine that with such an amount of training, an expert in a different domain than flying (such as an emergency doctor) could be trained to maneuver an aircraft. This would allow them to reach a destination where previously a designated pilot would have been needed.
In order to achieve the highest level of usability, user experience (UX) and controllability of the aircraft, one needs to have a detailed understanding of the human interaction with such a complex system. One approach that emphasizes the importance of considering the user, context and tasks of a system is the User-Centered Design (UCD) [8]. In this process, one of the first steps is the exploration of these aspects to holistically understand the use case scenario. One method to achieve this, is the Hierarchical Task Analysis (HTA) [9].
The goal of the research described here is to understand which (atomic) tasks need to be performed by the crew of an emergency helicopter for successful completion of a mission. In this case, this mission can be defined as the generic use case of transferring an emergency doctor to a patient in a remote area via an (generic) emergency helicopter and in a second stage via an eVTOL. Here, the HTA can help to understand, which tasks can (and need) to be adapted from a traditional multi-crew helicopter mission to be achievable by a single pilot with much less formal training in flying an aircraft in a later eVTOL setup.

3. METHOD

As the term "hierarchical" in the name HTA indicates, this approach decomposes a high level task sequence into multiple smaller subtasks. To achieve more detailed insights these subtasks are then split further, down to the level of actual actions of the operators in a process [9, 10]. This information is then enhanced by the "plans", which bring the actions into a logical order. In most cases they follow a linear ordering (denoted by a $>$), but sometimes parallel $(+)$, conditional $(?)$, or no particular ordering $(/)$ is also represented.
In order to transfer the information necessary for a future redesign of the HMI in an eVTOL, a two-step process was followed: first an HTA on the existing process with a traditional helicopter was performed. As in this traditional case a multi-person crew is operating the helicopter [11], the HTA was updated with information on which role performs which task. In the second step, the tasks were stripped down or reformulated to be achievable by a less trained single pilot (in this case an emergency doctor) in an eVTOL with SVO capabilities.
For the HTA described in this research, the mission was limited to a generic transfer of an emergency doctor to a patient in a remote area under Visual Flight Rules (VFR). As long as there a no eVTOL systems available that have the load capacity and space available to also transport the patient back to a clinic, this is the most probable scenario of (early) eVTOLs in the air ambulance service [5]. It also showcases a scenario, in which it should (from a task perspective) be possible to substitute a multi-person crew with a single pilot/doctor, as in a case of a patient transport, one member of the crew would need to monitor the patient on the transfer to the hospital.
The task decomposition for the HTA was based on multiple literature sources [5, 11–16]. These were based on the alerting and dispatching process in the German, Austrian and US American emergency services. Although, HTAs are usually based on first-hand accounts of the stakeholders in a process [10], the use of multiple literature sources from different perspectives allowed for a more "generic" look at the process as this avoids biasing of the results trough focusing on the accounts of pilots only used to their environment and helicopter type.
In the second step after the compilation of the HTA, the different subtasks and actions were analyzed based on the assumption of a single-pilot cockpit in an eVTOL context. Here it was also included that the assumed single pilot would be an emergency doctor with no (extensive) formal flight training. Through this process, those subtasks and actions that could not be performed by a single, lightly-trained operator were either eliminated or substituted by an automation-supported action. The goal of this step was the identification of tasks in the process, where future solutions need to be developed in order to support the operator in such a scenario.
As a mode of presentation for the HTA, the modernized table form was chosen [10]. This form allows for easy forward and backward tracking of the different subtasks and is more concise than the graphical form for such a complex scenario. To facilitate a comparison between the traditional helicopter emergency mission and a (possible) future process with an eVTOL, both processes are put next to each other. For reporting reasons, the HTA has been cut off after the stay at the emergency location has ended. A complete HTA with the return to the hospital has been performed but many steps are overlapping with the travel to the emergency location and are therefore not reported here.

4. RESULTS

The results of the HTA and adaptations for a future eVTOL context are reported in Table 1. The complete process of alerting of the crew and traveling to the emergency location can be split up into seven main tasks (listed at the beginning of the table). These main tasks are then split up into subtasks and further down to the action level. These can always be traced back by their superordinate number.
Major changes in the sequence of tasks can especially be found in the startup procedure for the eVTOL and the helicopter. To reduce training time and also make it possible for the (lightly-trained) pilot to focus on the actual main task of flying, also tasks such as interpreting Notice to Air Missions (NOTAMs) and weather charts and radio communication have been reduced and shifted to back end, automated systems. This is especially necessary as there are no other crew members available that the tasks could be shifted to.

Superordinate		Task component—operation or plan: Traditional helicopter mission		Adaptation for single pilot eVTOL mission
1		Approach a patient at remote location using an emergency helicopter under VFR		Approach a patient at remote location using a eVTOL with a single pilot under VFR
		Plan 1: Helicopter emergency crews are on standby and wait for a call from the dispatcher		Plan 1: [ED] is on standby and waits for a call from the dispatcher
	P1:	1 > 2+3 > 4 > 5 > 6 > 7 > 8 > 9 > 10	P1:	1 > 2 > 3 > 4 > 5 > 6 > 7 > 8 > 9 > 10
	1.1.	Receive information about emergency from dispatch	1.1.	Receive information about emergency from dispatch
	1.2.	Prepare travel to emergency location	1.2.	Prepare travel to emergency location
	1.3.	Prepare helicopter for departure	1.3.	Prepare eVTOL for departure
	1.4.	Leave station to emergency location	1.4.	Leave station to emergency location
	1.5.	Navigate to emergency location	1.5.	Navigate to emergency location
	1.6.	Land at emergency location	1.6.	Land at emergency location
	1.7.	Stay at location	1.7.	Stay at location
1.1.		Receive information about emergency from dispatch		Receive information about emergency from dispatch
		Plan 1.1: Helicopter emergency crew needs to gather all information for upcoming mission		Plan 1.1: [ED] needs to gather all information for upcoming mission
	P1.1:	*1 > 2+3 > EXIT*	*P1.1:*	*1 > 2+3 > EXIT*
	1.1.1.	Receive inital call from dispatch	1.1.1.	Receive inital call from dispatch
	1.1.2.	Be informed about type of emergency from dispatch	1.1.2.	Be informed about type of emergency from dispatch
	1.1.3.	Be informed about location of emergency	1.1.3.	Be informed about location of emergency
1.1.1.		Receive inital call from dispatch		Receive inital call from dispatch
		Plan 1.1.1: Helicopter crew must hear about an emergency		Plan 1.1.1: [ED] must hear about an emergency
	P1.1.1:	*1+2 > EXIT*	*P1.1.1:*	*1+2 > EXIT*
	1.1.1.1.	[ALL] Monitor call system (e.g. via FME/DME or via radio/phone)	1.1.1.1.	Monitor call system (e.g. via FME/DME or via radio/phone)
	1.1.1.2.	[ALL] Respond to call (e.g. via FME/DME or via radio/phone)	1.1.1.2.	Respond to call (e.g. via FME/DME or via radio/phone)
1.1.2.		Be informed about type of emergency from dispatch		Be informed about type of emergency from dispatch
		Plan 1.1.2: Helicopter crew must be informed about type of emergency		Plan 1.1.2: [ED] must be informed about type of emergency
	P1.1.2:	*1+2 > EXIT*	*P1.1.2:*	*1+2 > EXIT*
	1.1.2.1.	[HEMS TC] Gather information from dispatch	1.1.2.1.	Gather information from dispatch
	1.1.2.2.	[HEMS TC] Be informed about other emergency services en route	1.1.2.2.	Be informed about other emergency services en route
1.1.3.		Be informed about location of emergency		Be informed about location of emergency
		Plan 1.1.3: Helicopter crew must be informed about location of emergency		Plan 1.1.3: [ED] must be informed about location of emergency
	P1.1.3:	*1/2 > 3 > 4 > EXIT*	*P1.1.3:*	*1 > EXIT*
	1.1.3.1.	[HEMS TC] Receive GPS/Lat.-Lon. Position	1.1.3.1.	Receive GPS/Lat.-Lon. Position directly to digital device (e.g. to an EFB)
	1.1.3.2.	[HEMS TC] Receive description of location based on map-markers/landmarks		
	1.1.3.3.	[HEMS TC] Note down information about emergency on notepad (digital or pen and paper)		
	1.1.3.4.	[ALL] Coordinate with rest of crew		
1.2.		Prepare travel to emergency location		Prepare travel to emergency location
		Plan 1.2: The travel to the emergency location must be planned by a crew member		Plan 1.2: The travel to the emergency location must be planned by the [ED]
	P1.2:	*1+2 > EXIT*	*P1.2:*	*1+2 > EXIT*
	1.2.1.	Plan route to emergency location	1.2.1.	Plan route to emergency location
	1.2.2.	Check weather conditions	1.2.2.	Check weather conditions

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1.2.1.	Plan route to emergency location Plan 1.2.1: The actual route must be planned by the [HEMS TC] *P1.2.1: 1 > 2 > 3 > EXIT*	Plan route to emergency location Plan 1.2.1: The actual route cannot be easily planned by the [ED], therefore needs to be pre-rendered *P1.2.1: 3 > EXIT*
	1.2.1.1. [HEMS TC] Check NOTAMs for possible changes in airspace	
	1.2.1.2. [HEMS TC] Check map for location	
	1.2.1.3. [HEMS TC] Note down route in accordance with map and NOTAMs	1.2.1.1. Receive pre-planned route on EFB that respects NOTAMs
1.2.2.	Check weather conditions Plan 1.2.2: The route must be matched with current weather conditions by the [HEMS TC] *P1.2.2: 1/2 > 3 > 4 > 5 > EXIT*	Check weather conditions Plan 1.2.2: The weather cannot be judged by the [ED], therefore needs to be prerendered *P1.2.2: 5 > EXIT*
	1.2.2.1. [HEMS TC] Open weather information service	
	1.2.2.2. [HEMS TC] Contact ATC weather service	
	1.2.2.3. [HEMS TC] Compare weather information with planned route	
	1.2.2.4. [HEMS TC] Replan route based on weather information	
	1.2.2.5. [HEMS TC] Write down replanned route	1.2.2.5. Receive pre-planned route on EFB that respects weather advisories
1.3.	Check status of the helicopter Plan1.3: While [HEMS TC] prepares the route, [PILOT] checks the helicopter and prepares for takeoff *P1.3: 1 > 2 > 3 > 4 > EXIT*	Check status of the eVTOL Plan1.3: The [ED] must make sure that the eVTOL is operational before starting up the aircraft *P1.3: 1 > 2 > EXIT*
	1.3.1. Check if helicopter is operational	1.3.1. Check if eVTOL is operational
	1.3.2. Startup engine	1.3.2. Startup engine
1.3.1.	Check if helicopter is operational Plan 1.3.1: While [HEMS TC] prepares the route, [PILOT] checks the status of the helicopter *P1.3.1: 1 > 2 > 3 > 4 > 5 > 6 > 7 > 8 > EXIT*	Check if eVTOL is operational Plan 1.3.1: After the call has been received, the [ED] must check the aircraft *P1.3.1: 1 > 2 > 3 > 4 > EXIT*
	1.3.1.1. [PILOT] Check with ground crew about current status	1.3.1.1. Check with ground crew about current status
	1.3.1.2. [PILOT] Perform outside check of necessary systems	1.3.1.2. Perform outside check of necessary systems
	1.3.1.3 [PILOT] Board helicopter	1.3.1.3 Board eVTOL
	1.3.1.4. [PILOT] Check battery, fuel pump, and generator switches	1.3.1.4. Let aircraft perform self-test routine
	1.3.1.5. [PILOT] Check engine oil, generator, etc. lights on	
	1.3.1.6. [PILOT] Test annunciator panel, all lights on	
	1.3.1.7. [PILOT] Check strobe, nav, landing lights	
	1.3.1.8. [PILOT] Release rotor brake	
1.3.2.	Startup Engine Plan 1.3.2: After status of helicopter is clear, the engine can be turned on *P1.3.2: 1 > If area clear? Y > 2 N > EXIT > 3 > 4 > EXIT*	Startup Engine Plan 1.3.2: After status of eVTOL is clear, the engine can be turned on *P1.3.2: If area clear? Y > 2 N > EXIT > 3 > EXIT*
	1.3.2.1. [PILOT] Check outside area for obstacles/clearance	1.3.2.1. Check outside area for obstacles/clearance
	1.3.2.2. [PILOT] Flip the starter switch	1.3.2.2. Flip the starter switch
	1.3.2.3. [PILOT] Monitor and wait for turbine parameter stabilisation	1.3.2.3. Monitor and wait for turbine parameter stabilisation
	1.3.2.4. [PILOT] Flip the master avionics switch and wait for radio power up	
	Plan 1.4: When helicopter is in operating state and route is planned, the helicopter can leave the station *P1.4: 1 > If required by law? Y > 2 N > 3 > EXIT*	Plan 1.4: When eVTOL is in operating state and route is planned, it can leave the station *P1.4: If required by law? Y > 2 N > 3 > EXIT*
	1.4.1. Board all crewmembers	
	1.4.2. Inform ATC about flight plan	1.4.2. Inform ATC about flight plan
	1.4.3. Takeoff from landing pad	1.4.3. Takeoff from landing pad

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1.4.1.	Board all crewmembers Plan 1.4.1: When engine is running all required crewmembers can board the helicopter *P1.4.1: 1 > 2 > 3 > EXIT*	
	1.4.1.1. [HEMS TC + ED] Open Doors of helicopter 1.4.1.2. [HEMS TC + ED] Board helicopter 1.4.1.3. [HEMS TC + ED] Close doors	
1.4.2.	Inform ATC about flight plan Plan 1.4.2: If necessary at the location or for the planned route, inform ATC about flight plan *P1.4.2: 1 > 2 > 3 > EXIT*	Inform ATC about flight plan Plan 1.4.2: If necessary at the location or for the planned route, ATC must receive flight plan *P1.4.2: 1 > EXIT*
	1.4.2.1. [HEMS TC] Turn frequency button to the right frequency 1.4.2.2. [HEMS TC] Press push to talk button to contact ATC 1.4.2.3. [HEMS TC] Confirm flight path with ATC	1.4.2.1. Check that aircraft has established a link to ATC radio data channel
1.4.3.	Takeoff from landing pad Plan 1.4.3: Perform a takeoff from the landing pad *P1.4.3: 1 > 2 > 3 > 4*	Takeoff from landing pad Plan 1.4.3: Perform a takeoff from the landing pad *P1.4.3: 1 > 2 > 3 > 4*
	1.4.3.1. [PILOT] Pull collective to increase power to gain altitude 1.4.3.2. [PILOT] Use pedals to rotate aircraft to correct heading 1.4.3.3. [PILOT] Pull cyclic to increase backward momentum for CAT-A-Takeoff 1.4.3.4. [PILOT] Climb to decision altitude	1.4.3.1. Use power input device to increase power 1.4.3.3. Pull inceptor to increase backward momentum for CAT-A-Takeoff 1.4.3.4. Climb to decision altitude
1.5.	Navigate to emergency location Plan 1.5: When cleared from the landing pad, the aircraft can travel to the emergency location *P1.5: 1 > 2 + 3 + 4 + If neccessary/possible in the area ? Y > 5 N > + 6 + 7 > EXIT*	Navigate to emergency location Plan 1.5: When cleared from the landing pad, the aircraft can travel to the emergency location *P1.5: 1 > 2 + 3 + 4 + If neccessary/possible in the area ? Y > 5 N > + 6 + 7 > EXIT*
	1.5.1. Change course to emergency location 1.5.2. Avoid unsuitable terrain 1.5.3. Avoid unsuitable weather 1.5.4. Avoid other aicraft or obstacles in the air (drones, bird flocks) 1.5.5. Stay in contact with ATC and other aircraft 1.5.6. Stay in contact with emergency service provider dispatch 1.5.7. Control aircraft	1.5.1. Change course to emergency location 1.5.2. Avoid unsuitable terrain 1.5.3. Avoid unsuitable weather 1.5.4. Avoid other aicraft or obstacles in the air (drones, bird flocks) 1.5.5. Stay in contact with ATC and other aircraft 1.5.6. Stay in contact with emergency service provider dispatch 1.5.7. Control aircraft
1.5.1.	Change course to emergency location Plan 1.5.1: After takeoff, navigate towards the emergency location *P1.5.1: 1 + 2 > EXIT*	Change course to emergency location Plan 1.5.1: After takeoff, navigate towards the emergency location *P1.5.1: 1 + 2 > EXIT*
	1.5.1.1. [PILOT] Use cyclic and pedals to adjust course of the aircraft 1.5.1.2. [PILOT] Push cyclic forward to increase momentum towards the destination	1.5.1.1. Use inceptor(s) to adjust course of the aircraft 1.5.1.2. Push inceptor forward to increase momentum towards the destination
1.5.2.	Avoid unsuitable terrain Plan 1.5.2: On the way to the emergency location, unsuitable terrain has to be avoided *P1.5.2: 1 + 2 > 3*	Avoid unsuitable terrain Plan 1.5.2: On the way to the emergency location, unsuitable terrain has to be avoided *P1.5.2: 1 + 2 > 3*
	1.5.2.1. [PILOT] Check outside view for unsuitable terrain or buildings 1.5.2.2. [HEMS TC] Check map for unsuitable terrain or areas 1.5.2.3. [PILOT] Adjust course to avoid unsuitable terrain	1.5.2.1. Check outside view for unsuitable terrain or buildings 1.5.2.2. Check navigation display for unsuitable terrain or areas 1.5.2.3. Adjust course to avoid unsuitable terrain

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1.5.3.	Avoid unsuitable weather Plan 1.5.3: On the way to the emergency location, unsuitable weather has to be avoided *P1.5.2: 1 + 2 + 3 + 4 > If weather can be avoided ? Y > 5 N > 6 > EXIT*	Avoid unsuitable weather Plan 1.5.3: On the way to the emergency location, unsuitable weather has to be avoided *P1.5.2: 1 + 2 + 3 + 4 > If weather can be avoided ? Y > 5 N > 6 > EXIT*
1.5.3.1.	[HEMS TC] Contact ATC weather services to check weather status	Receive information about problematic weather on display in aircraft
1.5.3.2.	[HEMS TC] Contact emergency service ground units to be informed about weather status	Contact emergency service ground units to be informed about weather status
1.5.3.3.	[PILOT] Check outside view for unsuitable weather	Check outside view for unsuitable weather
1.5.3.4.	[PILOT] Check weather radar for unsuitable weather	Check weather radar for unsuitable weather
1.5.3.5.	[PILOT] Perform avoiding maneuver for unsuitable weather	Perform avoiding maneuver for unsuitable weather
1.5.3.6.	[PILOT] Abort mission	Abort mission
1.5.4.	Avoid other aicraft or obstacles in the air (drones, bird flocks) Plan 1.5.4: On the way to the emergency location, other aircraft and obstacles in the air have to be avoided *P1.5.4: 1 + 2 + If possible/necessary in the area? Y > 3 N > EXIT*	Avoid other aicraft or obstacles in the air (drones, bird flocks) Plan 1.5.4: On the way to the emergency location, other aircraft and obstacles in the air have to be avoided *P1.5.4: 1 + 2 > EXIT*
1.5.4.1.	[PILOT] Check outside view for other aircraft or visually identifiable obstacles	Check outside view for other aircraft or visually identifiable obstacles
1.5.4.2.	[PILOT] Check radar display for other aircraft	Check radar display for other aircraft
1.5.4.3.	[PILOT] Contact ATC to be informed about other aircraft and known obstacles	
1.5.5.	Stay in contact with ATC and other aircraft Plan 1.5.5: On the way to the emergency location, the crew must stay in contact with ATC if required/possible in the area *P1.5.5: 1 > 2 > 3 > EXIT*	Stay in contact with ATC and other aircraft Plan 1.5.5: On the way to the emergency location, the crew must inform ATC about current route *P1.5.5: 1 > EXIT*
1.5.5.1.	[PILOT + HEMS TC] Change ATC frequencies based on area using dial	Check that ATC data link is still operational
1.5.5.2.	[PILOT + HEMS TC] Monitor radio traffic on the frequency	
1.5.5.3.	[PILOT + HEMS TC] Push button on radio control panel to talk to respond to radio traffic	
1.5.6.	Stay in contact with emergency service provider dispatch Plan 1.5.6: On the way to the emergency location, the crew must stay in contact with the emergency service provider dispatch and other units *P1.5.6: 1 > 2 > 3 > EXIT*	Stay in contact with emergency service provider dispatch Plan 1.5.6: On the way to the emergency location, the crew must stay in contact with the emergency service provider dispatch and other units *P1.5.6: 1 > 2 > 3 > EXIT*
1.5.6.1.	[PILOT + HEMS TC] Use secondary radio panel to tune frequency of emergency service provider dispatch	Use secondary radio panel to tune frequency of emergency service provider dispatch
1.5.6.2.	[PILOT + HEMS TC] Monitor radio traffic on the frequency	Monitor radio traffic on the frequency
1.5.6.3.	[PILOT + HEMS TC] Push button on cyclic or secondary radio control panel to talk to respond to radio traffic	Push button on inceptor or secondary radio control panel to talk to respond to radio traffic

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1.5.7.	Control aircraft Plan 1.5.7: On the way to the emergency location, the pilot must control the helicopter *P1.5.7: 1 + 2 + 3 > If neccessary? Y > 4 N > EXIT > If neccessary? Y > 5 N > EXIT*	Control aircraft Plan 1.5.7: On the way to the emergency location, the pilot must control the eVTOL *P1.5.7: 1 + 2 + 3 > If neccessary? Y > 4 N > EXIT > If neccessary? Y > 5 N > EXIT*
	1.5.7.1. [PILOT] Monitor engine parameters (temperature, fuel flow etc.) via multi-purpose display or dedicated instruments	1.5.7.1. Monitor engine parameters (temperature, fuel flow etc.) via multi-purpose display or dedicated instruments
	1.5.7.2. [PILOT] Monitor flight parameters (altitude, attitude, heading) via PFD or dedicated instruments	1.5.7.2. Monitor flight parameters (altitude, attitude, heading) via PFD or dedicated instruments
	1.5.7.3. [PILOT] Check outside view and "gut" feeling for current altitude and momentum	1.5.7.3. Check outside view and "gut" feeling for current altitude and momentum
	1.5.7.4. [PILOT] Change parameters of engine performance via knobs and control systems	1.5.7.4. Change parameters of engine performance via knobs and control systems
	1.5.7.5. [PILOT] Change flight parameters via inputs on primary control elements	1.5.7.5. Change flight parameters via inputs on primary control elements
1.6.	Land at emergency location Plan 1.6: When arriving at the emergency location, the aircraft has to land *P1.6: 1 > 2 > 3 > 4 > EXIT*	Land at emergency location Plan 1.6: When arriving at the emergency location, the aircraft has to land *P1.6: 1 > 2 > 3 > 4 > EXIT*
	1.6.1. Survey landing location for suitable spot	1.6.1. Survey landing location for suitable spot
	1.6.2. Perform 360° rotation around possible landing location	1.6.2. Perform 360° rotation around possible landing location
	1.6.3. Laterally position aircraft for landing location	1.6.3. Laterally position aircraft for landing location
	1.6.4. Descend until touchdown	1.6.4. Descend until touchdown
1.6.1.	Survey landing location for suitable spot Plan 1.6.1: When arriving at the emergency location, the crew has to look for a suitable location *P1.6.1 1 + 2 + 3 > EXIT*	Survey landing location for suitable spot Plan 1.6.1: When arriving at the emergency location, the pilot has to look for a suitable location *P1.6.1 1 + 2 + 3 > EXIT*
	1.6.1.1. [ALL] Check outside view for suitable landing location	1.6.1.1. Check outside view for suitable landing location
	1.6.1.2. [ALL] Coordinate with remaining helicopter crew to look for appropriate landing location	1.6.1.2. Coordinate with remaining helicopter crew to look for appropriate landing location
	1.6.1.3. [PILOT + HEMS TC] Use radio to coordinate with ground units for suitable landing location	1.6.1.3. Use radio to coordinate with ground units for suitable landing location
1.6.2.	Perform 360 degree rotation around possible landing location Plan 1.6.2: When a possible landing location has been found, it should be surveyed from above *P1.6.2: 1 > 2 + 3 + 4 > If suitable for landing Y > EXIT N > 5*	Perform 360 degree rotation around possible landing location Plan 1.6.2: When a possible landing location has been found, it should be surveyed from above *P1.6.2: 1 > 2 + 3 + 4 > If suitable for landing Y > EXIT N > 5*
	1.6.2.1. [PILOT] Descend to 1,000ft	1.6.2.1. Descend to 1,000ft
	1.6.2.2. [PILOT] Use collective to maintain altitude in a hovering state	1.6.2.2. Use power input device to maintain altitude in a hovering state
	1.6.2.3. [PILOT] Use cyclic and pedals to perform lateral rotation around possible landing position	1.6.2.3. Use inceptor(s) to perform lateral rotation around possible landing position
	1.6.2.4. [PILOT] Visually inspect the possible landing location for obstacles and terrain	1.6.2.4. Visually inspect the possible landing location for obstacles and terrain
	1.6.2.5. [PILOT] Find different location	1.6.2.5. Find different location
1.6.3.	Laterally position aircraft for landing location Plan 1.6.3: If the landing location is suitable, the aircraft can be maneuvered above it *P1.6.3: 1 + 2 + 3 > 4 > EXIT*	Laterally position aircraft for landing location Plan 1.6.3: If the landing location is suitable, the aircraft can be maneuvered above it *P1.6.3: 1 + 2 + 3 > 4 > EXIT*
	1.6.3.1. [PILOT] Use the cyclic and pedals to position aircraft to keep the landing spot in direct sight (i.e. on the right side)	1.6.3.1. Use the inceptor(s) to position aircraft to keep the landing spot in direct sight (i.e. on the right side)
	1.6.3.2. [PILOT] Use the cyclic and pedals to approach the landing spot laterally	1.6.3.2. Use the inceptor(s) to approach the landing spot laterally
	1.6.3.3. [PILOT] Descend to 300ft	1.6.3.3. Descend to 300ft
	1.6.3.4. [PILOT] Come to a stop in order to do a quick out-of-ground-effect (OGE) hover check	1.6.3.4. Come to a stop in order to do a quick out-of-ground-effect (OGE) hover check

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1.6.4.	Descend until touchdown	Descend until touchdown
	Plan 1.6.4: When aircraft has been positioned laterally, the helicopter can land	Plan 1.6.4: When aircraft has been positioned laterally, the eVTOL can land
	P1.6.5: 1 + 2 > 3 > EXIT	*P1.6.5: 1 + 2 > 3 > EXIT*
	1.6.5.1. [PILOT] Push down collective to reduce power and descend	1.6.5.1. Use power input device to reduce power and descend
	1.6.5.2. [PILOT] Monitor descend progress on altimeter	1.6.5.2. Monitor descend progress on altimeter
	1.6.5.3. [PILOT] Feel and see touchdown on altimeter	1.6.5.3. Feel and see touchdown on altimeter
1.7.	Stay at location	Stay at location
	Plan 1.7: After aircraft has landed, the medical crew can disembark and help the patient	Plan 1.7: After aircraft has landed, the [ED] can disembark and help the patient
	P1.7: 1 > 2 +3 + 4 > 5 > EXIT	*P1.7: 1 > 4 > 5 > EXIT*
	1.7.1. Let emergency personnel disembark	1.7.1. Disembark
	1.7.2. Stay in contact with ATC and emergency service provider dispatch	
	1.7.3. Keep area clear for future takeoff	
	1.7.4. Ensure good condition of aircraft	1.7.4. Ensure good condition of aircraft
	1.7.5. Take emergency personnel back on board	1.7.5. Reembark
1.7.1.	Let emergency personnel disembark	Let emergency personnel disembark
	Plan 1.7.1: After helicopter has landed, the emergency personnel has to disembark	Plan 1.7.1: After eVTOL has landed, the [ED] has to disembark
	P1.7.1: 1 > 2 > 3 > EXIT	*P1.7.1: 1 > 2 > 3 > EXIT*
	1.7.1.1. [PILOT] Turn off engines	1.7.1.1. Turn off engines
	1.7.1.2. [PILOT] Monitor spindown process trough outside view and on instrument	1.7.1.2. Monitor spindown process trough outside view and on instrument
	1.7.1.3. [PILOT] Communicate disembarkation process with crew	1.7.1.3. Disembark aircraft
1.7.2.	Stay in contact with ATC and emergency service provider dispatch	
	Plan 1.7.2: After emergency personnel has disembarked, [PILOT] stays with the aircraft and monitors radio traffic	
	P1.7.2: 1 > 2 > EXIT	
	1.7.2.1. [PILOT] Dial in right frequency with ATC and emergency service provider dispatch on radio	
	1.7.2.2. [PILOT] Monitor and respond to radio traffic	
1.7.3.	Keep area clear for future takeoff	
	Plan 1.7.3: While at the location, [PILOT] and [HEMS TC] have to make sure that the area stays clear of people and obstacles	
	P1.7.3. 1 > If necessary? Y > 2 N > EXIT	
	1.7.3.1. [PILOT + HEMS TC] Watch outside area for obstacles and people	
	1.7.3.2. [PILOT + HEMS TC] Clear area of possible obstructions	
1.7.4.	Ensure good condition of aicraft	Ensure good condition of aicraft
	Plan 1.7.4: While at the location, [PILOT] has to make sure that the aircraft remains in good condition	Plan 1.7.4: After finishing the patient support, the [ED] has to make sure that the aircraft remains in good condition
	P1.7.4: 1 + 2 > EXIT	*P1.7.4: 1 + 2 > EXIT*
	1.7.4.1. [PILOT] Perform outside check on aircraft	1.7.4.1. Perform outside check on aircraft
	1.7.4.2. [PILOT] Check displayed parameters of aircraft	1.7.4.2. Check displayed parameters of aircraft

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1.7.5.	Take emergency personnel back on board Plan 1.7.5: After the mission of the emergency personnel has completed, they have to enter the aircraft again *P1.7.5: 1 > 2 > 3 > EXIT*		Reembark Plan 1.7.5: After checking the aircraft, the ED has to enter the aircraft again *P1.7.5: 1 > 2 > 3 > EXIT*
	1.7.5.1. [HEMS TC + ED] Open Doors of helicopter		1.7.5.1. Open door of eVTOL
	1.7.5.2. [HEMS TC + ED] Board helicopter		1.7.5.2. Board eVTOL
	1.7.5.3. [HEMS TC + ED] Close doors		1.7.5.3. Close door

Note. FME = Funkmeldeempfänger. DME = Digitaler Meldeempfänger. GPS = Global Positioning System. EFB = Electronic Flight Bag. VFR = Visual Flight Rules. ED = Emergency Doctor

TAB 1. The Hierarchical Task Analysis (HTA) of a emergency helicopter and (future) eVTOL mission

5. DISCUSSION

As eVTOLs are discussed as an addition in the context of air-based emergency services, it is necessary to understand, what this means in terms of the actual operations [4, 5] One part of this process is the analysis of the tasks that need to be performed by the (future) pilot(s) of such systems. Following the concept of SVO, it is possible that such a pilot did not receive extensive training as helicopter pilots nowadays [3].

The HTA reported here, showed that for a large part of the operations in a generic emergency mission, tasks are overlapping between an existing helicopter mission profile and an imagined future eVTOL mission. Although the technical properties of the different eVTOL concepts are still mostly not finalized yet, it can be seen, that general flying tasks in such a scenario (such as navigation and control of the aircraft) would still be necessary. This can also be attributed to the fact, that in such an emergency mission almost always involves landing the aircraft in an area without a dedicated landing spot. This is a major difference from the usually discussed “taxi service”.

However, major differences can be observed when it comes to the role definition of the pilot in such a scenario. If one assumes that for load capacity, space and range reasons, the crew of an emergency eVTOL would be reduced to two or even only one crew member, the roles and responsibilities would certainly need to be adapted [5]. This is especially reflected in the domain of radio communications, as this is a task, that is usually shared between the pilot and the Helicopter Emergency Medical Services Technical Crew Member (HEMS TC) of a helicopter. In a future aircraft, it would be preferable that an information exchange between the pilot and external parties (such as Air Traffic Control, ATC, or other aircraft) would be more data-link based.

As the pilot in the scenario described here is also not as extensively trained in all of the subdomains of aviation (such as meteorology or the reading of NOTAMS etc.), tasks that could be solved on an organizational level or trough a technical solution should be used. One example of this is the automated route planning based on the location of the aircraft and the emergency that should take place in the back end of the organization. Also, the aircraft should possess extensive self-diagnosis functions with clear error and possible solution reporting as the pilot might not have the detailed technical knowledge to diagnose the problems in detail.

5.1. Limitations and Outlook

One major limitation that is introduced into the redesign of the mission profile reported here, is the single-pilot operation. In case of a pilot incapacitation, there is currently no backup layer available that would prevent the aircraft from crashing – making the pilot of the eVTOL a single point of failure that should be avoided. In the usually imagined scenario for eVTOLs – air taxi services – such an incapacitation could possibly be mitigated by the fact that there is a passenger on board. For the emergency mission profile described here, such a mitigation does not exist. However, the general topic of single-pilot operations and possible solutions (e.g. health monitoring and remotely piloting an aircraft in an emergency) has been under discussion for a while now (e.g. [17]). It can therefore be assumed, that in the future, a solution for this problem will exist.

For the research reported here, it should be noted that the task analysis was compiled based upon publicly available material on the process of an emergency mission. Although such an approach is generally a good first step, it is highly recommended to validate and reformulate such an analysis together with experts from the field [9]. It is therefore planned to perform qualitative interviews and focus groups with the different disciplines that are part of such a helicopter emergency mission (pilot, HEMS TC and the emergency doctor). The information gathered from such discussions will directly influence the design of a future HMI for such a scenario.

5.2. Conclusion

The HTA performed for this research is a first step in the UCD process of the display configuration for an eVTOL in the emergency mission context. It allows the identification of the different subtasks and actions that need to be performed by the crews in such scenarios. For the future it can now be used to systematically redesign the HMI of future aircraft operating in such scenarios.

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