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Mission Flexible – Minimum General Requirements for a UAV Training Concept

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ABSTRACT

Nowadays, more and more UAV missions are conducted within diverse setups. Different setups require flexible training concepts. By interviewing nine expert UAV operators on experience and evaluation of training they had participated in over the past, this study aims to explore training aspects that strengthen safe-efficient UAV operator skills – as flexible as possible and as detailed as necessary. The study results offer a framework of minimum requirements for UAV training that can inspire and support other researchers who aim to develop UAV training concepts. These include recommendations on individual training, crew training, emotional regulation and fear management, as well as on training structure and environments.

Keywords: RPAS, UAV, UAV-training, Minimum training requirements

INTRODUCTION

Training concepts for unmanned aerial vehicle (UAV) crews are often based on the well-defined requirements of the respective work organization. The more formalized a UAV organization is structured, the more specific a suitable training concept can be elaborated. UAV missions are often run in such highly structured frameworks, such as in executive forces (cf. Hiltner, 2013, Glade, 2000, Aleksander, 2018, Stuchlík and Kubíček, 2021). In these cases, they require very specific training concepts that are not always accessible to the general population. However, UAV missions are also conducted within more flexible setups. This is the case in civilly or privately used remotely piloted aircraft systems (RPAS), such as in local rescue organizations (cf. Lieb et al., 2021) or agriculture (Eves et al., 2009). Sometimes, if not often, this flexibility is needed. This is the case when novel UAV organizations are developed with iteratively elaborated operational and training concepts. In other cases, flexibility is necessary when already existent UAV organizations use different drones or deal with constantly varying flight missions. Current findings provide information on the necessary prerequisites regarding the selection criteria of UAV personnel and their expected competencies or skills to be developed (cf. Howse, 2011, Rose et al., 2013, Rose et al., 2014). However, this information can only be used to a limited extent to draw conclusions

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about training in terms of form and content. Some of these competencies are already required for a trainee qualification, others are enforced during training – tailored to the needs of specific UAV organizations. A recent study reveals recommendations on training of key competences in civilian UAV crews (Schmidt, 2021). Nevertheless, uniform standards and minimum requirements for UAV crew trainings are scarce in existing literature and very context-dependent (e.g. type of organization, degree of automation of the UAV, etc.). Therefore, our goal within this study is to explore minimum requirements for UAV training and to describe them in such a way that they can flexibly serve the development of UAV training concepts. According to Carreta et al. (2016), a minimal crew in the military often consists of air vehicle operators (AVO) and sensor operators (SO). Either an RPAS pilot, or a GCSO (in modern setups with increasing automation that do not require manual remote piloting) could take on the role as an AVO. For security reasons, a crew could be supported by a so-called safety pilot who can fly the RPAS manually (Dauer et al., 2015). In this present study, we therefore include training related to operators who control the RPAS, or operate an attached device on the drone (e.g. camera), only. We are aware that a UAV crew can include many other actors (launch assistants, airspace observers, etc.). However, since we assume the most flexible cases and a minimal crew, this study focus is on RPAS pilots, GCSOs and SOs.

METHOD

Sample

We interviewed four RPAS pilots and five GCSOs to generate a broad set of relevant themes regarding form and contents of a minimal general training concept. Within the interviewed RPAS pilots and GCSO, circa two third had experiences with either fixed wing drones or rotor drones and a third was familiar with flying both. None of them had undergone a standardized selection process to be an UAV operator. Some of them fly privately with model aircraft and drones and all of the interviewees operate RPAS within a professional framework. Among their professional tasks, they are involved in flight experiments and therefore have good experience with drone flights under a wide variety of flight conditions and technical parameter settings. More than half of the study participants had contributed to training content and its performance evaluation before.

Material and Procedure

A semi-structured interview guide was used as a guideline. General predefined themes within the subject matter interview included experience and evaluation of training the interviewees had participated in over the past, regarding individual training, crew training and training environments. The interviews took place online via Skype for Business (Microsoft, 2022) between November 25^{th} and December 7^{th} 2022 and lasted between 60 and 80 minutes. Before starting the interview, the study participants received a short presentation about the goals of the study and the procedure of the interview. A pilot interview was recorded. Since not all participants were comfortable being recorded, we decided on standardizing the interviews by taking notes during the interview over a shared screen. Thus, the interviewees were able to interfere in order to correct for potential mistakes. The notes were subsequently imported to NVivo (QSR International Pty Ltd., 2020) Then, we applied a thematic analysis inspired by the method proposed by Braun and Clarke (2006).

RESULTS

An overview of the main themes and subthemes can be found in **Table *1***. Each theme will be presented in detail in the following sections.

Individual Training

The interviews reveal that each RPAS operator, depending on the specific role they perform during a UAV mission, works with job-specific instruments and executes tasks that are very role-specific. In the following two sections, we present the results on general recommendations for *(a) Instrument related training* and *(b) Task specific training for high workload tasks*.

(a) Instrument related training

In the interviews, operators highlight that the instruments used in training should be as close as possible to the instruments used in real UAV missions. From a cognitive perspective, according to the interviewees, excellent familiarity with the remote-control system along with the mission software and hardware is essential. The more operators know the instruments the more they trust them and their ability to handle them in flight. This should include 1-to-1 training with the software for GCSOs and experience with the setup of the hardware (e.g., alignment of antennas, establishment of a communication link, retrieval of the data link). It became clear several times during the interviews that there is no unique design for a ground control station. Especially software seems to differ, and their design is not always assessed as being intuitive for the operator. Therefore, it is important for GCSOs to

Table 1. Main themes and subthemes of the thematic analysis.

Main themes	Subthemes
(1) Individual Training	*(a) Instrument related training* *(b) Task specific training for high workload tasks*
(2) Crew Training	*(c) Communication* *(d) Mutual role understanding and internalized coordination between crew members*
(3) Emotion Regulation and Fear Management Training	*N/A*
(4) Training Structure and Multiple Training Environments	*(e) Theoretical education and practical familiarization* *(f) Dry run* *(g) Flight simulation training* *(h) In situ training*

acquire technical knowledge and develop a good understanding of the software and the associated system. This also includes a skill development of system monitoring in order to draw conclusions about a system's current state. As one interviewee notes, each GCSO must learn to interpret the monitored data to be able to draw conclusions about the RPAS's system state (e.g., temperature state and associated conclusions about the drone's general system state and possible consequences). As the same operator states, a higher familiarity with the system decreases the workload when monitoring different parameters simultaneously. Sensor operators (if present in a UAV Crew) should have knowledge acquisition and skill development similar to GCSOs, with regard to their used instruments. Pilots, who manually control the RPAS, should also train with the UAV used in the latter mission if available. At least, they should train with a 1-to-1 model of the aerial vehicle and control elements. According to one interviewee, it is essential for pilots to not only understand but also to test the physical characteristics of the flight object and train to adapt to them. Generally speaking, GCSOs and RPAS pilots should know the functions and limitations of their instruments inside and out so as not to be negatively surprised during operations, especially if slight deviations occur. On a physiological level, sensory-motor skills must be deepened in training so that each operator can react instinctively and adapt automatically to the situation. According to the interviewees, the internalization of these skills can only succeed if the instruments used in repeated training are the same as those used in the real flight situation.

(b) Task specific training for high workload tasks

Regarding task specific training, the operators stated that every UAV crew member clearly needs to know their tasks and train for them. There seems to be no specific recommendation on the training load and frequency but a good rule of thumb would be to increase training for tasks that appear difficult to individual operators. Moreover, one should set a particular training focus on high workload tasks.

For GCSOs, the workload was mentioned to be highest in head-down system monitoring tasks and in critical situations that require quick and adapted action. Regarding head-down system monitoring, a GCSO must constantly screen different data to infer information about the drone's system status. Surprisingly, according to the interviewed operators, multitasking is not necessarily responsible for the increased workload in head-down system monitoring, but rather the intensive comparison of actual values with target values and in some cases, a subsequent adjustment. Rapid risk assessment and the capacity to act quickly can also lead to increased workload for GCSOs, especially when critical events occur (e.g. technical problem with the UAV). If the contingency or emergency cases have been defined and documented a priori, risks related to those use cases must be identified and evaluated quickly so that adequate measures can be applied according to a practiced scheme. In cases with unknown critical situations, a GCSO must be able to make a best guess about what is happening and make a quick decision on how to act (e.g. change settings, abort mission, contact a safety-pilot, etc.). In order to cope well with such high-workload situations, it is important to put a GCSO in these conditions during training. This way, they can learn how to react adequately and confident in a real UAV mission when workload peaks.

Sensor operators' workload mainly increases due to a high volume of work or decision making and action when approaching a target. According to the interviewees, a special training focus should be placed on contingency and emergency cases (e.g. camera lens is fogged up, amplifier does not work, other sensors do not react, etc.).

For pilots controlling the RPAS manually, difficult external conditions mainly were perceived to lead to increased workload. These can be, for example, unfavorable visibility conditions (e.g., sunlight blinding), extreme temperatures, strong winds. Specific mission-related flying can also increase workload, such as flying at low altitude (e.g., during noise measurements), interference with other airspace users, or flying by objects. The increase of workload may also depend on the type of RPAS being piloted. For example, for fixed-wing aircraft, takeoff and landing can occasionally be challenging. Aircraft such as gyroplanes are generally perceived to be a bit more difficult to fly because one often has a relatively small margin to fly it safely. As for any other potential crew member, contingency and emergency situations also can lead to increased workload. This is especially the case when the RPAS pilot only has to be on standby and intervene as a safety pilot when a GCSO hands over control of the drone. According to an interviewee, a standby mode can be very demanding for safety pilots because they have to maintain situation awareness even during a long period of inactivity and react quickly and correctly when they are demanded to do so.

Crew Training

Depending on the type of a RPAS as well as on the regulatory and organizational framework, a UAV crew may consist of one or more operators. If multiple operators are involved in a UAV mission, crew training is essential to the success of a UAV mission. The subthemes generated from the interviews and developed in this section include *(c) Communication* and *(d) Mutual role understanding and internalized coordination between team members*.

(c) Communication

According to all interviewees, smooth communication within a UAV crew is one of the most important criteria for a successful RPAS mission and therefore needs special attention in training.

As a general principle for safe and efficient communication in a UAV mission, study participants cited avoiding noise on the radio, which implies discipline and directed communication. More specifically, keeping the radio clear for important information is imperative to UAV operators. As the interviewees state, disciplined communication requires only one individual to speak when a message is transmitted by radio. In standard as well as in critical situations, clear and concise communication about current events is necessary within a team. To communicate safely and efficiently with each other, a message needs to be unambiguous. For example, saying *"RPAS is acting strangely"* is not a clear description of a state of the air vehicle. In such a case, the ambiguous information requires the message receiver to make an additional request, which can jam the radio and lead to delays in a mission. Especially in situations that necessitate quick action, the ambiguity of a message can lead to misunderstandings and significant avoidable errors. To practice directed and unambiguous communication, standardized communication can be helpful. The interviews reveal that standardized phraseology is not mandated in all UAV crews, but is certainly considered useful. In the absence of formalized communication rules, according to several study participants, it is up to a UAV crew to develop their own phraseology for their specific use cases and train it, tailored to its mission. In doing so, the crew needs to determine the use cases that should be communicated in a standardized manner, those which are mission-dependent, and those which allow for some flexibility in execution. In general, the interview participants consider a standardized phraseology to be helpful, especially in recurrent situations (e.g., announcements for speed relative to air, etc.). Several interviewees pointed out that it may also be helpful to occasionally follow aviation phraseology standards, both in terms of vocabulary and procedures. As an example, a RPAS pilot cited a handover procedure in which the operator in charge says *"you have control"* to the operator who is to take over, the latter confirming the handover by *"I have control"*. Reading back a piece of information and then counting down are also standards used in other areas of aviation that were assessed to be helpful in a UAV mission. According to the interviewees, a certain flexibility in communication is okay – as long as the information is identical in context and there is no room for interpretation. As an example, an interviewee stated that there was no ambiguity in saying *"engine is at nominal speed"* or *"engine is at 100%"* but that the specific expression can vary individually, especially when teams change frequently and new crew members need to be integrated. The consistent use of certain trigger expressions could also contribute to safety-efficient communication – as an example, a GCSO cites the expression *"link lost"*, which informs crew members about communication with the UAV being lost.

In addition to establishing a certain standardization of language within a UAV crew, the interviews revealed the importance of training situations in which increased team communication is required. According to the interviewed RPAS operators, these include formal checklists to be completed in the pre-flight phase and debriefing discussions post-flight, which require a certain level of team interaction. In addition, there are often mission-relevant and operator-specific aspects that individual operators like to establish during briefing or discuss for improvement when needed in debriefing. These aspects include all sort of information about which individual operators like to be notified during the mission, for example the crossing of certain waypoints or battery levels. Increased team communication may also occur during take-off and landing, depending on the RPAS in use. In these stages, especially fixed-wing drones often require optimal interaction between multiple actors (e.g., RPAS pilot with GCSO or with launch assistants). Regarding communication during the flight, the interviewed operators stated that their workload is often saturated with tasks that are mission relevant. Nevertheless, increased communication may occur during specific situations, such as when a GCSO needs to interact with a safety pilot who can fly the RPAS manually or with a SO (e.g., an operator controlling a camera attached to the UAV and evaluating visual data). Between safety pilots and GCSOs, communication of a drone's status data and handover procedures must be practiced beforehand. Coordination between manual RPAS pilots or GCSOs with a sensor operator must also be trained, especially when dealing with an object of interest (e.g. decision making is needed in terms of approach, loiter or deviating from a planned route). Finally, it is important to practice communication that can occur in safety critical situations. According to the interviewed UAV operators, these can be contingency and emergency cases that were identified a priori. Communication in such pre-identified cases can be trained very well in preparation for a mission. On the other hand, the interviewees highlighted that not all scenarios are foreseeable. Therefore, it is important to train crew members to communicate under increased uncertainty and master these situations with confidence.

To conclude the topic of communication training, it should be noted that some UAV missions require communication with external individuals that should be adequately trained. Regarding these situations, interviewed participants mainly mentioned organizational and legal aspects with involved actors (e.g., air traffic control, executive units) or otherwise affected stakeholders of a mission.

(d) Mutual role understanding and internalized coordination between crew members

Next to communication training, the interviewed participants emphasized the importance of operators' role definition and understanding. Prior to a UAV mission, each operator needs to be aware of their role and the associated responsibilities within the team. Moreover, they need to develop an understanding for their crew members' roles and responsibilities. Procedures that are handled in teamwork should be defined a priori and, if possible, documented in as much detail as possible (e.g. in a concept of operations). This allows crew members to train commonly handled processes always according to the same scheme and perform better in a later UAV mission. This is especially important in situations where one must act fast and has no time to fathom about what to do. In a well-trained team, crew members give each other space so that the person in charge can adequately take care of a critical situation and react adequately. Practicing these situations repeatedly is crucial until they are integrated safely and efficiently and can be applied at all times. Another closely related aspect brought up by the interviewees is the training of the crew members' awareness as to who is in charge of RPAS at a given point of time in a mission. According to the operators, there must never be a vacuum of responsibility in any situation. In other words, there needs to be clarity at all times as to who has control over the UAV, and this needs to be practiced as well. To conclude, one interviewee points out that a rigid role definition inherently leads to a loss of flexibility, which is preferable in a well-established concept. In contrast to a rigid role definition concept, the same operator comments that more flexible systems can be acceptable when conducting an RPAS flight together with a familiar, well-coordinated crew that has good situational awareness. Familiarity in a well-coordinated team is a theme that contributes greatly to a smooth UAV operation for all interviewees. The rationale for this argument is that a well-coordinated team requires little verbal interaction since the individual crewmembers are able to understand the role of the other operators and manage to perform their designated role at the right time. Within the context of familiarity and impeccable team coordination, several interviewees additionally cited a feeling of reliability and mutual trust, which is established over time with common training and flight experience. As one interviewee notes, crew training is about developing a collective sense of responsibility and building a team that is interested in succeeding: Top-down training should be avoided and the needs of the trainees should be addressed so that they are perceived and valued.

Emotion Regulation and Fear Management Training

As we learned from the interviewees, there are certain events and chains of events that can evoke unfavorable emotions in operators such as acute panic or latent fear across multiple missions, which then can lead to other undesirable outcomes. Such trigger situations can be unpredictable events but also contingency and emergency cases. In well-prepared missions, contingency and emergency cases clearly are defined and operators should know how to act, at least in theory. Frequently mentioned cases concern problems with the RPAS (e.g. loss of communication, flight mechanical problems, deviant drone behavior, etc.), suddenly appearing obstacles (e.g. other airspace users, bird strike, etc.). There is also a risk of concatenation of such cases. In any case (single or multiple chain event), these are situations that lead to increased workload in the operators and require them to be able to decide and act quickly regarding the progress of the mission and the *"fate"* of the drone. It is important that the operator does not panic at such a moment, but learns to remain calm, decides and acts safely, independently from the financial cost or the impact on future UAV missions. Even though a drone might crash, it is also important that operators do not develop latent fear of operating a drone and continue to build trust in the system and their ability to operate it. Emotion regulation training and fear management is an aspect that operators need to train on an individual level but also within a crew. Individually, operators have to practice mental training to develop pragmatism. To learn that material objects can be replaced and to overcome the latent fear of destroying expensive objects can be trained with crash drones. Within a team framework, fear management training can be trained collectively. This can be done by extensive mission preparation or debriefing decisions objectively after an event. In any case, it is important to never blame an operator in charge for their decision to crash a drone. Within a crew, it is perceived to be important to have each other's back.

Training Structure and Multiple Training Environments

All interviewees agreed that the complexity of the training units should be increased step by step to avoid overcharge of future operators, keep the motivation of training going and reduce the risk of making mistakes under real flight conditions. To improve operators' knowledge and skills, the increase of complexity can be supported by a gradual step from theoretic to practical aspects of training or be approached iteratively. It was important to the majority of operators that, in addition to general training, mission-relevant training always to occur close in time to a mission. Multiple training environments are devised in *(e) Theoretical education and practical familiarization*, *(f) Dry run, (g) Flight simulation training, and (h) In situ training*.

(e) Theoretical education and practical familiarization

Theoretical education and practical familiarization with the RPAS and related instruments in question[1] are a crucial basis for further training steps. According to the interviewees, an operator can obtain information in a variety of ways and form by accessing manuals and technical literature or asking experts and experienced colleagues. Often, RPAS manufacturers offer a training regarding their product. Common topics researched include technical aspects of a RPAS in question (e.g., flight behavior, system state information, etc.) and related instrumentation (e.g., operation, standard problems, etc.), or mission-relevant topics (e.g., procedural differences between land and sea operations, etc.). Operators can work through mission-relevant training aspects, both theoretically and practically, individually or in a group. Hands-on familiarization with the RPAS material before using it is also part of the first steps of a training.

(f) Dry run

A cost-effective variant of the training sessions is the dry run. UAV operators can run through and document scenarios in their heads, either individually or as a team. In this way, team communication, checklists or procedures can be optimized and internalized. Furthermore, contingency and emergency cases can be defined, discussed and documented for risk preparation. A dry run can also be a helpful way to prepare for a specific mission after other training sessions that increase real-world conditions. Several interviewees describe that they often mentally review checklists, procedures, and what-if scenarios before a flight. This also helps collectively as mental preparation and to increase risk awareness.

(g) Flight simulation training

One of the most commonly mentioned training environments is flight simulation training. With increasing reality, this type of training can be applied to develop an as-good-as-real feeling operating the drone. Depending on the simulation software and the simulation environment, more or less types of simulations (e.g., desktop simulation; hardware-in-the-loop; team interaction, etc.) can be performed to improve flying and monitoring skills or to test the limits of a system (e.g., stall). Several operators appreciate the use of simulators with a 1-to-1 model of the remote control or monitoring instruments that will be used to fly or monitor the drone in a real mission. Flight simulator training allows operators to individually practice all possible critical situations recorded in the simulator (e.g., engine failures, rudder failures, high winds, etc.). In more elaborate forms, flight simulation training can be performed within a team.

[1] To stay within the scope of this study, we deliberately do not detail all the necessary qualifications that operators need in order to obtain a license for a specific RPAS category. Rather, we assume the training of staff that already is authorized to operate RPAS.

(h) In situ training

In situ training is the most real form of training and can take place in scaled-down or detailed contexts. As a beginner, for example, one can train with an instructor or an experienced colleague at the airfield. As we learned in the section in chapter 3 Emotion Regulation and Fear Management Training, inexpensive remote-control aircraft (e.g., crash drones) can also be used within this context, as operators estimate themselves being tenser in a field test than in a simulation. If one has individually mastered one's tasks in a field test and has gone through all other training levels, one can perform a field test together with the crew in the next step. To conclude, carrying out a detailed debriefing after a field test was important to the interviewees.

DISCUSSION AND CONCLUSION

The aim of the study was to explore general minimum requirements for a training concept that should make UAV operations cross-organizational and cross-mission possible. The results show that many important aspects of training can already be implemented in one's UAV organization, both on an individual and on a crew level. For instance, acquiring enough theoretical knowledge, practicing as much as possible, dry runs, and in situ training can already be applied anywhere. In addition, there are also flight simulation software in every price range that can be built more or less elaborately. In a team, tasks and responsibilities in the context of UAV operations should be clearly defined. If these are dynamic, a clear assignment should be made before each mission. Moreover, team debriefings are advised following each exercise or operation. Within this context and reflected by our results, it is important to practice error management avoiding blaming, based on classic aviation as to ask why an incident happened and not who'd done it (cf. Minor, 2013).

It should be noted that we were unable to interview SOs and therefore relied on the statements of GCSOs and RPAS pilots. Methodically spoken, it would have been more correct to record the interviews and to make a thematic analysis based on the interview transcriptions. However, as the notes were taken together with the interviewees, we are positive that the most important aspects were documented.

In conclusion, our results show a rich panel of general recommendations of training contents and training environments that can remain flexible in the minimum requirement range, or be refined for a specific UAV organization if needed. The findings should be understood as a framework of minimum requirements for UAV training that can inspire and support other researchers who aim to develop initial training concepts. For the future, we would like to see more studies on the development and validation of training concepts for UAV crews. Complementary to self-reported information about training for UAV crews, it would be beneficial to see more data on the efficacy of training concepts regarding safe and efficient operator performance. In line with this perspective and based on the results of this study, we plan to develop a training concept within a follow-up study.

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