Enhancing Unmanned Aerial System Training: A Taxonomy of Knowledge, Skills, Attitudes, and Methods

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The burgeoning use of Unmanned Aerial Systems (UASs) has, regrettably, not been met with an appropriate integration of training science into UAS training efforts. At best, current UAS training efforts are fragmented; at worst, they are ineffective (Stulberg, 2007). However, this need not be the case. Though nascent, the UAS literature has identified many necessary knowledge, skill, and attitude (KSA) components of UAS operation. This article works to aid the UAS training community in combining practice with science. In order to accomplish this goal, the emerging UAS knowledge base is collected herein as a taxonomy of KSAs. These KSAs are joined by a listing of training methodologies that can be used to impart them to UAS operator teams. Finally, these KSAs and methods are used to resolve example training deficiencies drawn from the literature.

INTRODUCTION

Despite increased use throughout civilian and military organizations around the world, the training of Unmanned Aerial System (UAS) teams has failed to adopt advances in the science of training. UAS teams are interdependent operators working together to operate a complex system of systems (Cooke & Shope, 2005). Thus, the science of team training is especially applicable to the education of UAS operators. While research into UAS operations and the human factors requirements thereof is progressing (Cooke, Pringle, Pedersen, & Connor, 2006), this scientific information is not getting into the hands of training developers. Without knowledge of the science, those in charge of developing UAS training can do little to improve existing training or create new, more effective curricula. In order to assist the UAS community, this article seeks to elucidate the process of using psychological science in improving UAS training. In order to do so this article will: 1) describe the UAS training problem, 2) delineate the knowledge, skills, and attitudes (KSAs) required for UAS operation, 3) list the general and specific training methods available for UAS training, and 4) show examples of how specific UAS training deficiencies indicate necessary KSAs and training methods.

PROBLEM: UAS TRAINING

One of the primary indicators of the deficiency in UAS training comes directly from the UAS community. While the US Air Force attempts to harness the capabilities of unmanned systems on an organizational scale, there is great internal discord over how operators should be trained (Stulberg, 2007). Indeed, Stulberg (2007) notes while examining the plight of UAS operators:

> The overload on operators and sensor operators not only circumscribes training, but also compels them to develop operational practices and standards on the fly, with little interaction with Air Force doctrinal authorities or pilot community. (p. 261)

Given this deficiency, it is very timely to attempt to inject the tenets of the science of training into the UAS training process. In order to do so, the unique challenges and competencies inherent to UAS operation must be identified. For example, there is a general deficiency in the communications between commanders and UAS operators (Durlach, 2007). These deficiencies, in turn, relate back to specific knowledge, skill, and attitude components that are not being conveyed in training. By understanding these KSAs, it is possible to determine which methodologies can be used to train them. And, in turn, by determining which methods are useful for training the KSAs that represent deficiencies in a particular problem set, remedies for faulty training begin to emerge.

UAS KNOWLEDGE, SKILLS, AND ATTITUDES

Examining the KSAs inherent to UAS training provides a simple way by which to classify the items that training should convey to operators. A general taxonomy of KSAs for team-based training has already been established in the literature (Salas, Burke, & Cannon-Bowers, 2002). However, for any given context, there are specific KSAs that focus on unique aspects of a task or situation. Thus, a complementary listing of UAS-specific KSAs is warranted. The KSAs described herein have been drawn from the nascent UAS literature in order to supplement this general taxonomy (see Table 1). These KSAs were gathered by searching psychology and military research databases (e..g, PsycInfo, DTIC, etc.) with the search terms “UAS teams”, “unmanned aerial vehicle teams”, “UAS training”, and related permutations thereof.

UAS Knowledge

Knowledge in the context of KSAs comprises the memory structures used to recognize and utilize environmental information. Effectively, this refers to any stored or dynamically obtained information required to complete a task. In order to supplement the knowledge components delineated in the general literature (Salas, Burke, & Cannon-Bowers, 2002), UAS-specific knowledge is described here. One way to further the UAS knowledge components is to split them into groups based on their focus. Within the UAS realm, knowledge is primarily split along the line of human-focused items and equipment-focused items.

Knowledge	Skill
Human-Focused	Flight skill
Culture	Long-term monitoring
Contingency behavior	Target search
Workload	Instrument monitoring
Fatigue	Mission monitoring
Information overload	Navigation
Distraction	Team leadership
Mission awareness	Delegation
Human locations	Team composition
Human activities	Mission planning
Human identities	Plan understanding
Human characteristics	Replanning
Human intentions	Stress management
Human activity dependencies	Decision making
Larger mission	Problem solving
Commander’s/mission intent	Risk assessment
Shared situation awareness	Visual scanning strategy
Equipment-Focused	Handoff
System feedback	Communication
Operational threats	Inter-team communication
Command set	Information flow
Constraints	Collaboration
Automation reliability	Coordination
4D Spatial Relationships	Teamwork skills
Performance envelope	**Attitude**
Level of automation	Risk perception
Latency	Risk taking behavior
Equipment knowledge	“Kill Chain” stress
Task knowledge	Complacency
Shared situation awareness	Overtrust
	Undertrust
	Calibrated trust
	High value opportunity

Table 1: UAS-specific KSAs.

Human-focused knowledge. Generally, human-focused knowledge in UAS operation deals with understanding of, and insight into, individual and team operator states. For example, knowledge of the culture of team members requires understanding the professional and regional background of team members (Sharma & Chakravarti, 2005). Individual knowledge also comprises meta-task knowledge, such as understanding current workload level (Wilson, 2002), operator fatigue (Walters, French, & Barnes, 2000), information overload (Drury & Scott, 2008), and distraction (Drury & Scott, 2008). Related to knowledge of these potential detractors of performance is knowledge of necessary contingency behaviors (McCarley & Wickens, 2005). Similarly, situation awareness in UAS can be divided into mission awareness (i.e., understanding the mission and progress made toward it), human location awareness (i.e., knowledge of the distribution of team members, and human activity awareness (i.e., knowledge of the current tasks of team members; Drury & Scott, 2008). In addition to the individual situation awareness required by operators, shared situation awareness is required by the UAS team (Freedy et al., 2007). These situation awareness knowledge components are, in turn, related to the components of the mental models that UAS operators have. Individuals in a UAS team require knowledge of the identities, characteristics, intentions, and activity dependencies the other human operators of the team (Drury & Scott, 2008). Additionally, understanding how the current operation fits into the larger mission and into the commander’s intent (Durlach, 2007) serve to provide context to the operator’s actions.

Equipment-focused knowledge. Beyond these human-centered knowledge items, the complex UAS system requires understanding of the equipment being operated. The most basic set of equipment knowledge deals with the specific UAS system: its command set, operational threats, constraints, performance envelope, and the level of automation within the system (Drury & Scott, 2008) as well as its reliability (Dixon, Wickens, & Chang, 2004). These items differ based on the specific UAS being operated, but knowledge of the system within the operational environment is dynamic for each operation. The dynamic elements of equipment knowledge include the feedback provided by the system (Tvaryanas, Thompson, & Constable, 2007), the four-dimensional (i.e., spatial and temporal) state of the system (Drury & Scott, 2008), the latency or lag for sending commands (Billings & Durlach, 2008). Each of these static and dynamic items forms a general equipment knowledge set, which comprises knowledge of the terminology and technical details of the UAS (Freedy et al., 2007) as well as a task knowledge set that describes the operation of the system (Durlach, 2007).

UAS Skills

If knowledge components are those items required for individuals and teams to perform a task, skills are how these individuals and teams actually perform them (Cunningham, 2008). Though not all members of the team are responsible for flight, the most basic skill for UAS operation is flight skill (Stulberg, 2007). The most universal category of skills individuals operating UASs must employ are monitoring-related. Monitoring in the UAS task includes long-term monitoring (i.e., vigilance; Wilson, 2002), target search (Dixon, Wickens, & Chang, 2004), instrument monitoring (Hopcroft, Burchat, & Vince, 2006), mission monitoring (Freedy et al., 2007). and navigation and path monitoring (Dixon, Wickens, & Chang, 2004). Related to these monitoring abilities is the visual scanning strategy that operators employ in visual searches (McCarley & Wickens, 2005).

Because of the dynamic nature of team-based system operation, as well as the general uncertainty and risk present in military undertakings, UAS operators must be able to adapt to shifting demands. Decision making, problem solving, and risk assessment (Tvaryanas, Thompson, & Constable, 2007; Wilson, 2002) are required to deal with a mutable mission. The shifting demands of the operational environment also necessitate an ability to deal with the inevitable stress that arises (Sharma & Chakravarti, 2005).

The leader of a UAS operation must exhibit particular skills that other operators may not require. Team leadership (Sharma & Chakravarti, 2005), delegation (Durlach, 2007), team composition (i.e., the process of selecting team members; Durlach, 2007), mission planning (Freedy et al., 2007), understanding plan dissemination and re-planning as necessary (Durlach, 2007) are skills of UAS team leaders that have been revealed in the literature.

So far, these skills have been those exhibited by individuals rather than teams as a whole. The team itself, however, has skills that they must possess in order to ensure successful operation. These skills deal with inter and intra-team logistics, such as conducting handoff (McCarley & Wickens, 2005), general and inter-team communication (Bellur, Lewis, & Templin, 2002), managing information flow (Freedy et al., 2007), collaboration (Bellur, Lewis, & Templin, 2002), coordination (Durlach, 2007; Freedy et al., 2007). Based on these skills, it is evident that teamwork in general is necessary for the operation of a team-based UAS (Durlach, 2007).

UAS Attitudes

The final components of the KSA taxonomy are attitudinal, referring to the affective states and differences of team members. Attitudes comprise personal qualities such as initiative as well as emotional valuations such as opinions (Cunningham, 2008). The extant taxonomy of attitudes (Salas, Burke, & Cannon-Bowers, 2002) is expansive, but there are several unique attitudinal components of UAS operation that have been noted in the literature. Unlike the components in the UAS knowledge or skill categories, each of these attitudes is exhibited on an individual level.

Because UAS operation often takes place in a military setting, attitudes toward risk and risk taking are important to success. The perception of risk as well as degree of risk taking behavior (McCarley & Wickens, 2005) must be calibrated to levels that are acceptable for the mission. Combat operations require complex decision making driven by an understanding of the mission, but judging the value of targets of opportunity is often attitudinal in nature (Stulberg, 2007). Further, combat operations may place stress on operators due to their presence in the "kill chain", i.e., their work resulting in potential loss of life (Stulberg, 2007).

The semi-automated nature of UAS operation brings with it the host of automation-related attitude components that have long been a subject of discussion in the field of automation. Overtrust, undertrust, and complacency (Dixon, Wickens, & Chang, 2004) are all attitudinal threats to successful UAS operation. The optimum state of an operator as regards an automated system is calibrated trust (Dixon, Wickens, & Chang, 2004), and this is no different for operators of UASs.

TRAINING METHODS

Armed with a knowledge of which KSAs can be found within the UAS domain, it is necessary to examine the training methods available to instructors. Without knowledge of which methods target which KSAs, the taxonomy of UAS KSAs is merely an explanatory tool. Paired with a list of methodologies (see Table 2), it is possible to pair KSAs and methods in a manner useful to enhancing new and existing training. These training methodologies fall into four categories: general, knowledge-focused, skill-focused, and attitude-focused.

General Methods

General Methods	Knowledge Methods
Event-Based Training	Cross-Training
Scenario-Based Training	Multicultural Training
Self-Correction Training	**Skill Methods**
Guided Self-Correction Training	Team Coordination Training
On-the-job Training	Team Leader Training
Role Play	Virtual Team Communication Training
Simulations and Games	Behavior Modeling
Automation-enabled full flight simulation	Stress Exposure Training
UAS Simulation	Stress Inoculation
Embedded Instructional Agent	**Attitude Methods**
Simulation-based handoff scenario	Trust Tuning

Table 2: Identified training methods.

General methodologies can be used to train almost any of the UAS-specific KSAs identified herein. While they are broad techniques, this is not because of any defect in their methodologies. Rather, it is because of their flexibility. Event-based training and scenario-based training are similar techniques that attempt to elicit behaviors by situating training in complex environments and scenarios (Oser, Gualtieri, Cannon-Bowers, & Salas, 1999). These two techniques are applicable to the entire spectrum of UAS KSAs, as they are extremely flexible. Equally flexible are on-the-job training (Ford, Kozlowski, Kraiger, Salas, & Teachout, 1997) and role-play (Salas, Burke, & Cannon-Bowers, 2002) techniques, which also focus on producing specific behaviors. Self-correction training also employs scenarios, but allows team members to evaluate and improve individual and team behavior in guided or unguided settings (Smith-Jentsch, Cannon-Bowers, & Salas, 1998). Self-correction methods are best employed for team-oriented KSAs, as the presence of the team allows each team member to share their knowledge and insights.

A particularly large segment of the general training methods falls into the simulation and games subset (Cannon-Bowers & Salas, 2000). Simulations and games are replications of reality that focus on presenting specific aspects of a task or scenario. Within this subset, there exist a number of more adapted methodologies. For example, UAS simulation focuses on UAS knowledge and skill components (Jovanovic, Starcevic, & Obrenovic, 2007), while a simulation-based handoff scenario focuses on the narrower KSA set of handoff and communication (Berkenstadt et al., 2008). Automation-enabled full flight simulation is similar to general UAS simulation, though it incorporates automation aspects in order to train use of, and attitude toward, automation (Plat & Amalberti, 2000). Finally, embedded instructional agents work to provide additional contextual information within a simulation, such as elucidating 4D spatial relationships or guiding the development of flight skills (Ryder, Scolaro, & Stokes, 2001).

Knowledge-Focused Methods

The knowledge-focused methods available for UAS training focus on the operator team learning specific knowledge components together. Cross-training is a training method in which each team member is trained in the roles and responsibilities of the rest of the team (Salas, Cannon-Bowers, & Johnston, 1997). This allows an individual operator to have a knowledge base for what their team members are doing, how they are doing it, and how their own roles relate to theirs. Multicultural training works for a narrower set of UAS KSAs, working to impart a better knowledge set of the backgrounds of team members in both the traditional and organizational sense of culture (Hayes et al., 2004).

Skill-Focused Methods

The skill-focused methods are the most specific of the training methods outlined here. Most of these methods focus on training a particular skill or narrow set of skills. For example, team coordination training works to impart competence in handoff, communication, collaboration, and coordination (Entin & Serfaty, 1999). Similarly, virtual team communication training focuses on communication in a distributed setting (Warkentin & Beranek, 1999). Team leader training is focused on those aspects of communication that are required for successful organization of the operator team, such as delegation and mission planning (Tannenbaum, Smith-Jentsch, & Behson, 1997).

The above skills are primarily concerned with functions supporting team behavior. Stress exposure training and stress inoculation training can be performed with individuals in order to temper their resistance to the stressors inherent to operating a UAS (Driskell & Johnston, 1998; O'Donohue, Hayes, & Fisher, 2003). Both of these techniques work to impart coping skills by exposing trainees to specific stress scenarios.

The final skill-focused method is, unlike those discussed so far, fairly general within the realm of training skills. Behavioral modeling refers to a method that requires a participant to observe and then replicate the behavior exhibited by an instructor (Tannenbaum, & Yukl, 1992). This technique can be used to train most UAS skills identified herein, especially those that require little introspection on the part of the operator.

Attitude-Focused Methods

As the amount of UAS-specific attitude components is relatively small, the only method that is specific to a UAS attitude is trust tuning. Trust tuning works to alter attitudes regarding the future behavior of the UAS in order to reach a level of calibrated trust in automation (Miller, 2005). Other attitudinal outcomes are achievable through the use of the general methods previously described. Additionally, the general attitude components discussed in Salas, Burke, & Cannon-Bowers, 2002 have specific training techniques that are useful in imparting specific affective changes (e.g., team cohesion through team building exercises; Tannenbaum, Beard, & Salas, 1992).

EXAMPLE PROBLEM-KSA-METHOD GROUPINGS

Having established a taxonomy of UAS-specific KSAs and delineated a collection of methods that can be used to train these KSAs, it is now possible to examine how to remedy specific problems encountered as a result of inadequate UAS training. In this section two example problems that have been identified in the literature will be described. The specific KSAs relating to these problems will then be paired with training methodologies in order to highlight how to resolve these problems through applied science.

Impossible Reconnaissance Request

A common problem encountered in the field consists of a commander asking for reconnaissance of an area by means of a UAS when the weather (or other operational conditions) does not permit such an operation (Durlach, 2007). In this case, there is a deficiency in the commander's understanding of the UAS and its operation. Based on the UAS KSA listing, it is reasonable to presume that this problem is a knowledge-oriented one, and that it is likely equipment-related. Constraints, performance envelope, and equipment knowledge are three KSAs that would allow the commander to understand proper use of the UAS. Based on these KSAs, it is necessary to examine which methods could be used to convey these knowledge components. Because each of these KSAs is a knowledge item, a knowledge-specific method such as cross training would make for a good candidate. Cross training the commander with the rest of the UAS operators would provide the commander with a basic understanding of the system and its constraints, and should assist the commander in making appropriate reconnaissance requests.

Improper Handoff Procedure

Another problem that has arisen in shift-based UAS operation occurs when operators or teams of operators fail to transmit vital information about the mission and system to the next operator/team shift (McCarley & Wickens, 2005). This deficiency relates to one specific KSA rather than a series of KSAs, being directly tied to the handoff skill. Handoff is the formalized procedure wherein information is passed from one team to another. Conveniently, past research has produced a training technique that is specifically geared toward training teams in handoff procedures. A simulation-based handoff scenario would be most appropriate in conveying this skill to a team of operators, though other communication training techniques (e.g., team coordination training) may be appropriate as well.

CONCLUSION

Understanding where deficiencies in UAS training lie allows educators and curriculum designers to better design and improve their courses. These individual KSAs are also useful as a starting point for research into UAS training efficacy, as metrics can be capture performance in the context of specific KSAs. The UAS-specific KSA listing and the training methodologies described herein provide effective tools with which to analyze UAS training and the problems that arise during deployment. Combining these specific KSAs and methods with previously established team KSAs and methods (Salas, Burke, & Cannon-Bowers, 2000) creates a comprehensive taxonomy for UAS training. However, this effort is only a small portion of the work that can be done to support the UAS community. While the taxonomies developed herein and in previous research are useful tools, they must be made more accessible if they are to be adopted by the UAS training community. Given recent efforts to produce formal UAS training tracks in organizations around the world

(Stulberg, 2007), timely efforts of the scientific community are necessary to fill this training gap. Using the information contained herein as a starting point, rapid development of more effective UAS training should be possible. However, true integration of science and training requires a concerted effort from both communities, and it is hoped that this article can serve as a catalyst for further examination of the specific requirements of UAS training.

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