Team Coordination in UAV Operations

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The term “unmanned” in the context of unmanned aerial vehicle (UAV) operations is too often taken literally, overlooking the humans controlling, monitoring, collaborating, and coordinating from the ground. Promoting and improving the performance of the human component in the operation of UAVs is paramount and enhancing the coordination of the humans in the system is one of many important human factors issues which must be overcome. Research from the Cognitive Engineering on Team Tasks Laboratory has approached this problem with the development of a synthetic test-bed replicating UAV coordination in the lab. Findings from this synthetic task environment (STE) will be discussed in context of the implications that UAVs are in fact manned and require the attention of the human factors community.

Introduction

The Department of Defense defines unmanned aerial vehicles (UAVs) as powered aerial vehicles that do not carry human operators, use aerodynamic forces of lift, can fly autonomously or be piloted remotely, can be expendable or recoverable, and can carry lethal or non-lethal payloads (Blazakis, 2004). The role of UAVs in the military has rapidly expanded over the years such that every branch of the U.S. military deploys some form of UAV in their intelligence, surveillance, and reconnaissance operations. Recent U. S. military successes include a USAF Predator UAV operating in Iraq that successfully aided in finding Saddam Hussein (Rogers, 2004). Perhaps the most amazing fact from this is that the crew which was actively in control of the UAV, was located in Nellis AFB in Las Vegas, Nevada. Another more recent example took place in August 2004 when a Predator UAV armed with Hellfire missiles rescued a group of U. S. Marines pinned down by sniper fire in Najaf, Iraq. That Predator was also controlled from Nellis AFB in Las Vegas, Nevada. The worth of UAVs has become such that the militaries of every major power on the planet employs the use of UAVs including, but not limited to Germany, England, China, France, Canada, South Africa, and Israel.

The use of UAVs has also become so popular that many civilian uses have arisen, from security and law enforcement uses such as border and wildfire surveillance, to agricultural uses such as crop dusting and crop health monitoring. For example, the NASA ERAST Pathfinder has been successful in monitoring coffee fields in Hawaii for ripe beans, which has lowered operating costs and increased revenue for the company (Roeder, 2003). UAVs have been so successful, that future planned missions to Mars will see the use of UAVs to explore the Martian surface. Other uses for UAVs will eventually include communication relay and weather monitoring by high altitude-long endurance (HALE) platforms as well as surveillance and reconnaissance in the service of Homeland Defense.

UAV Mishaps

For all their successes and usefulness, the operational record of UAVs has been marred by high mishap rates which are frequently cited as a deterrent to the widespread use of UAVs. Mishaps as defined by the U. S. Navy, are unplanned events that directly involve naval aircraft, which results in $10,000 or greater cumulative damage to aircraft or personal injury. Under this classification, a “Class A” mishap is that in which the total amount of damage exceeds $1,000,000 or results in the destruction of the aircraft. The high mishap rate, which is currently 100 times higher than that of manned aircraft, has proved to be a deterrent to the military fully embracing the use of UAVs. For example, the Pioneer UAV has an unacceptable Class A mishap rate of 385 mishaps per 100,000 flight hours since 1986. In contrast, manned Naval aviation has a rate of 2 mishaps per 100,000 flight hours (Jackson, 2003). The Predator UAV, which has a total operational hour count of under 100,000 hours, has had 74 mishaps contrasted with a mishap rate of 8.1 per 100,000 flight hours for manned civil and commercial aircraft.

Schmidt & Parker (as cited in Fergusen, 1999), examined 107 mishaps that occurred between 1986 and 1993 and found that 59% were attributable to electromechanical failure and 33% were due to human errors attributed from crew selection and training, pilot proficiency, personnel shortages, operational tempo, and errors in teamwork and aircraft control. Seagle (as cited in Fergusen, 1999) also examined 203 mishaps from 1986 through 1997 and found that 43% of those were attributable to human error. One example of a mishap occurred when a Predator UAV encountered a fuel problem during a descent and upon entering instrument meteorological conditions, icing occurred and the engine lost power. The UAV crashed in an unpopulated wooded area so there were no casualties. It was determined that the operators' attention became too focused on flying the UAV in conditions they had rarely encountered. Ultimately, there was a lack of communication between the two operators during the emergency, which resulted in the mishap.

The increasing frequency and varied applications in which UAVs are being, and will be used, coupled with the high mishap rate speak to the need for more human factors research. There is much work to be done in many areas including automation, vigilance, feedback, procedures, crew selection, displays, training, coordination, and communication. Given today's emphasis on teamwork and the foreseeable future of UAV command and control possibly emphasizing teams of teams of UAVs working in concert in a heterogeneous network-centric battlefield, we have identified the coordination and command and control aspects of UAVs as a critical research issue.

Myths and Fallacies

Despite the apparent usefulness and worth of UAVs, and given their high mishap rate, very little human factors work in this area has been done. We believe that the lack of human factors work in the area is due to several myths and fallacies that surround the operation of UAVs. We feel that these false beliefs hide the fact that there is much research that is needed in this field. By shedding light on these fallacies, we hope to draw attention to the current human factors issues as well as any potential problems that might arise in future systems.

The Automation Fallacy

UAVs are highly automated. Platforms such as the Global Hawk are capable of taking off, flying missions, and landing, all fully autonomously. The belief is that more automation is better and if there is a problem, a person can simply step in and deal with it. However, over thirty years of sponsored research has shown that automation changes the human's task and not always in a positive manner. Many mishaps are attributed to the human being "out-of-the-loop," just as in manned aircraft such as commercial jetliners. We posit that one of the advantages of UAVs is that the humans have the ability to override the automation and perform dynamic re-tasking.

The Air Traffic Control Fallacy

Another fallacy concerns the belief that since air traffic controllers can monitor dozens of vehicles, UAV operators should also be able to handle multiple platforms at once. The fact here is UAV control tasks involve much more that monitoring and control of aircraft position. Many platforms such as the U. S. Army Shadow and the U. S. Navy Pioneer are controlled by stick and rudder controls. Dynamic re-tasking and re-planning maximally exploits the system. In addition, many believe that the state of the art is 1 operator per vehicle and that a 1:4 operator to vehicle ratio is a logical extension (Shope, DeJoode, Cooke, & Pedersen, 2004). However, the current state of practice demonstrates a 2:1 operator to platform ratio and current research suggests that a 1:n operator to UAV ratio will prove to be problematic.

The Manned Flight Fallacy

This fallacy stems from the belief that UAV flight is no different from manned flight. Since the UAV is a vehicle, piloting a UAV is similar to piloting an airplane in the cockpit, thus a single pilot should be sufficient. The truth is that a UAV is not simply a vehicle, but a system that includes ground control, operators, intelligence, weather personnel, maintenance personnel, and payload operators in addition to the UAV itself. This "piloting analogy" ignores years of studies on time lad, loss of visual cues, depth perception, and ignores the system functions that go beyond flight such as re-tasking, re-planning, and sensor operation.

The Unmanned Fallacy

That UAVs are unmanned, and even the name "unmanned," has propagated the myth that UAVs are indeed 'unmanned.' This notion could not be farther from the truth however as there are always humans in the loop at one point or another whether it is preprogramming a UAV to takeoff, fly a set of waypoints, and land autonomously, to the pilot that is actually controlling the UAV via stick and rudder controls. The fact that the UAV is uninhabited such that there is no actual flight crew onboard does not mean that it is unmanned. The two examples previously discussed above highlight the fact that even though the crews in control of the UAVs were roughly 7,000 miles away, there were nevertheless, humans involved in the loop. This "unmanned fallacy" assumes that since there are no humans in the loop, there is therefore, no need for human factors. However, data gathered from the examination of mishaps demonstrates that humans are indeed a part of UAV control and that human factors research should be an iterative part of the design and implementation of UAV systems as well the training of personnel and the development of operational procedures.

Principles of Command and Control

Advances in technology have increased the cognitive complexity of tasks and therefore, the need for teamwork has also increased. Teams operating in highly cognitive domains (e.g., aircraft cockpits, air traffic control, operating rooms) are required to plan, detect and interpret cues, make decisions, and perform as one coordinated unit. We define teams as a distinguishable set of two or more people who interact dynamically, interdependently, and adaptively toward a common and valued goal, who have each been assigned specific roles or functions to perform, and who have a limited life span of membership (Salas, Dickinson, Converse, & Tannenbaum, 1992). The collaborative cognitive processes that teams undergo are referred to as *team cognition*. Team cognition is more than the sum of the cognition of individual team members. Instead, it emerges from the interplay of the individual cognition of each team member and team process behaviors.

Why measure team cognition? Team cognition contributes to team performance now more than ever in today's cognitive tasks. Many organizations (military and civilian) hold the belief that teams are the solution to many problems. It is perceived that teams are better able to handle stress, are more adaptable in dynamic environments, make better decisions, and are more productive than individuals alone. Research on understanding team cognition and effective team performance has long been an area of intense focus for human factors, military, social, cognitive, and industrial/organizational psychologists (Cooke, Salas, Kiekel, & Bell, 2004).

Now, more than ever, issues of assessing team performance, training teams, and designing technological aids for effective team command-and-control performance are critical, yet highly challenging. How can team performance be measured? How can we characterize and assess cognitive skill at the team level? Can assessment occur without disruption of operational performance and can it occur in time for intervention? How is team cognition and performance impacted by training, technology, and team composition? Is team cognition different than the sum of the cognition of individual team members? What are effective training regimes or decision tools for these team members?

Our research program in the CERTT (Cognitive Engineering Research on Team Tasks) Laboratory is focused on these and other questions pertaining to team performance and cognition. Team coordination is characterized by timely and adaptive information exchange among team members. More specifically, command-and-control tasks in both military and civilian domains can be characterized as challenging from the perspective of the command-and-control team for a number of reasons including the; 1) unanticipated nature of the situation, 2) *ad hoc* formation of team structure, 3) lack of familiarity among team members, and 4) extended intervals with little or no team training. Items 3 and 4 are particularly relevant to military and civilian command-and control communities because there can be fairly long periods when command-and-control teams are not able to train and practice together, yet they are expected to be competent as soon as they are deployed. We view team coordination as central to team skill in command-and-control. In addition, for teams that stay together in a natural, operational setting (e.g., UAV teams) it is difficult to control the amount of exposure teams get to the operational tasks between laboratory sessions. Other goals of the CERTT Laboratory include the identification of issues and needs in the measurement of team cognition, the development and evaluation of new measures and the application of new measures and methods in which to better understand and evaluate team cognition.

The CERTT Laboratory

The heart of the CERTT Laboratory, shown in Figure 1, is a flexible synthetic task environment (STE) that is designed to study many different synthetic tasks for teams working on complex environments. STEs provide an ideal environment for study of team cognition in complex settings by providing a middle-ground between the highly artificial tasks commonly found in laboratories and the often uncontrollable conditions found in the field. We are currently studying team cognition with the use of an UAV-STE controlled by a three-person team whose mission is to take reconnaissance photographs. This current set-up is based on a cognitive task analysis of the ground control station of the Predator UAV operated by the U.S. Air Force (Gugerty, DeBoom, Walker, & Burns, 1999). The UAV-STE emphasizes many team aspects of tasks found in UAV operations such as planning, re-planning, decision-making, and coordination.

Figure 1. *CERTT Lab participant and experimenter consoles.*

The team members involved in this task are the Air Vehicle Operator (AVO) who flies the UAV by controlling the heading, altitude, and airspeed, the Payload Operator (PLO) who controls camera settings and takes reconnaissance photos, and the Data Exploitation, Mission Planning and Communications Operator (DEMPC) who plans the mission and acts as the navigator. More information on the CERTT Laboratory can be found in other publications (Cooke, Rivera, Shope, & Caukwell, 1999, Cooke & Shope, 2002).

Our Findings

Team Performance We use performance data as the criterion against which other measures (i.e., team process behaviors, taskwork knowledge, teamwork knowledge, situation awareness) can be evaluated. For instance, if one of our cognitive measures fails to predict performance differences, then it is not as useful as one that does. All interventions, personnel selection rules, manipulations, technological innovations, decision aids, or training strategies are of little importance if they have no impact on this bottom line. As a result, much of the team literature has focused on measures of team performance or effectiveness and findings that impact team performance or effectiveness (e.g., Salas et. al., 1992). In our UAV-STE, we rely on a composite measure of team performance that includes number of targets photographed, number of airspace violations, amount of consumables used (i.e. fuel, film), and time spent in alarm or warning state.

Thus far, we have completed 5 separate experiments which have examined team performance and cognition under varying circumstances including the co-location (all three members in the same room) vs. distribution (members located in different rooms) of team members, encouragement vs. discouragement of information sharing during breaks, and the “force-feeding” of teamwork and coordination information prior to the development of taskwork knowledge. Results from prior experiments indicate that the encouragement vs. discouragement of information sharing had no effect on team performance and that attempts to “force-feed” teamwork and coordination information were unsuccessful, suggesting a sequential dependence of knowledge development such that taskwork knowledge must precede teamwork knowledge. Our findings have also shown that geographic distribution of team members had no effect on performance. Distribution did however, have an effect on process behaviors and knowledge.

In addition to team performance, we measure process behavior in our UAV task through experimenter observations and ratings. Experimenters monitor behaviors such as communication, coordination, and leadership behaviors and rate them on a scale that indicates the observed quality of these behaviors. Also behavior is observed and rated at critical event junctures in the simulation. Overall, we find that process data can provide information where performance data do not. In some cases we find that outcome does not differ, but process does, providing some insight into the teams’ adaptive behaviors. In the experiment described above, we found that co-located and distributed teams behaved differently, but managed to obtain similar performance scores (Cooke, et. al., 2004). Without the process data we might have assumed that there was no impact of distributed or co-located settings, but in conjunction with process data, we now understand that team interactions were adaptive for their own environment and the adaptation of the best teams may provide insight for training or design interventions.

Overall, the lack of performance effects is good news for military and civilian agencies which have begun to embrace distributed command-and-control. This is especially beneficial for the operation of teams-of-teams of UAV operators that must coordinate and work in concert, yet are geographically distributed. However, a caveat here is that teams need to be free to adapt their coordination behavior to preserve performance effectiveness. Thus, command-and-control environments and procedures demand careful consideration of these human factors issues.

Team Practice In our UAV task we have found consistent and robust findings in regard to team skill acquisition and in some cases, retention of that skill. Individuals are trained to criterion on the AVO, PLO, or DEMPC task prior to working together as a team. Once they come together in a mission scenario as a team, it takes them 3-4 40-minute missions to reach asymptotic levels of team performance (Figure 2).

Our knowledge measures indicate that most taskwork and teamwork knowledge is stable by the first mission. The process and communications data, on the other hand, indicate that teams during this initial period of working together are learning how to coordinate of pass information back and forth in a timely and adaptive manner. There is also a hint of loss due to a retention interval when some teams returned after several weeks for their third session (after Mission 7). The study of retention intervals on coordination skills is currently being tested in the laboratory.

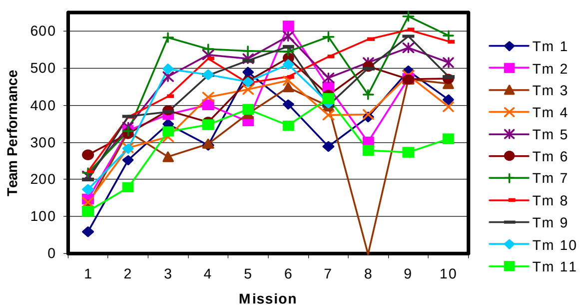

Figure 2. *Team performance of 11 teams over 10 missions. A long break occurred between Missions 7-8*

Team Communication Team communication is central in command and control tasks. Communication is also a critical mode by which coordination occurs, though it is possible to communicate in a variety of different ways (e.g., oral, gestural, computer messaging) and it is possible to coordinate implicitly without communication. In our UAV experiments we have found that communication patterns (both the content of what is said and the flow from person to person) are associated with team performance (Kiekel, Cooke, Foltz, & Shope, 2001).

Effective teams have different patterns compared to ineffective teams. Effective teams are generally more consistent in their communication patterns than ineffective teams. Workload influences patterns. Other subtle factors such as geographic distribution also influence communication patterns. Communication patterns change as teams acquire experience. Why are we interested in communication? It is not so much to train teams in ways to better communicate, thereby enhancing coordination, though that would be one approach. Rather we view communication as a readily available source of information on team cognition. Again, because we view team cognition as an emergent property of teams and believe that cognitive processing at the team level takes place in the interactions among team members, we see communication as a direct reflection of team cognition. Like team cognition, the communication-based measures should predict team performance, but should also provide additional diagnostic information. After having identified patterns associated with ineffective and effective teams, we are now exploring finer distinctions among teams in regard to team knowledge and team situation awareness that can be ascertained through analysis of communication data. We are also identifying was to automate this process with the ultimate goal of embedded and on-line communication analysis leading to a diagnosis of a team's cognitive state.

Implications for UAV Operations

The success of UAVs in both military and civilian applications is much more complex than is commonly thought as demonstrated by the various myths and fallacies that exist regarding their operation. The complexity of operations is also likely to become even higher as more UAVs take to the skies, flying longer, more varied missions. While this may not be as important an issue to military forces operating in sparsely populated areas of the world, this is of special concern in populated civilian areas. The Federal Aviation Administration (FAA) has mandated that in order for UAVs to operate in the national airspace (NAS), certain safety issues must be addressed. These issues include the need for collision avoidance, and over-the-horizon subsystems development, leading up to the establishment of certification processes and operating criteria (National Aeronautics and Space Administration, 2001). These concerns stem from the simple fact UAV operation in the NAS is hazardous because there is no pilot onboard that can aviate, navigate, communicate, diagnose problems, and scan the environment for traffic.

Despite the inevitable advances in collision avoidance and over-the-horizon technologies, chances of mishaps will still become higher due to the increased traffic and coordination requirements on teams of UAVs. Coupled with the aspect of UAV operators working in teams of teams, controlling multiple platforms, and interacting with manned air traffic and air traffic controllers, the need for interventions stemming from the study of performance, training, communication and coordination in UAV operations will become a valuable commodity. In addition, our research has shown that the coordination among only 3 ground control personnel controlling a single UAV is highly complex. Studies have yet to be conducted in the coordination of all personnel (i.e. operators, maintenance staff, air traffic control) involved in the operation of a single system. In addition, future military doctrine calls for an increase in the UAV to operator ratio where it is thought that one operator will control multiple UAVs. What will be the impact on coordination? What will happen when single operators controlling multiple UAVs must coordinate and interact with other operators performing the same task, air traffic control, and other manned aircraft?

It is the goal of the CERTT Laboratory to explore team coordination and in the process, dispel the myths and fallacies that reside within UAV operations. Raising the awareness of the myths and issues involved in UAV operations within the human factors community will increase the amount of research done in this budding area. Such research will not only benefit UAV operators, but will answer questions such as those above, as well as increase the safety of air operations in both military and civilian sectors.

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