Coordination in Distributed Unmanned Aircraft Systems

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Our objectives in this paper are to: (1) explicate the link between UAS accidents and coordination, and (2) to provide prescriptive guidelines for improving coordination in distributed UAS. To accomplish these goals we will review the literature on team coordination, examine how distribution impacts that process, identify the areas in which coordination plays a critical role in UAS incidents and accidents, and conclude with some prescriptions for improving UAS team coordination.

Unmanned aircraft systems (UAS) have been in use since 1967, when the Israeli Army used radio-controlled model aircraft to take aerial photographs behind Egyptian lines (Nelson & Bolia, 2006). Although still primarily used in military applications, there are a great many potential uses for UAS in the civilian sector, including aerial surveillance, oil, gas and mineral exploration, logistics, scientific research, and search and rescue (Adams, Humphrey, Goodrich, Cooper, Morse, Engh, & Rasmussen, 2009; DeGarmo, 2004; Xiang & Tian, 2011). Despite the growing acceptance of UAS, a cause for concern is the current UAS accident rate, which is sometimes estimated to be 100 times that of manned aircraft (Hing & Hing, 2009). For example, the U.S. Air Force recorded six serious UAS accidents (resulting in a fatality, permanent disabling injury, or property damage of $1 million or more) per 100,000 flight hours in fiscal year 2007 and 2008. Air Force accident rates for crewed aircraft in 2009 and 2010 were 0.72 and 0.80 per 100,000 flight hours respectively (Goyer, 2010; Nullmeyer, 2009). For all military UAS combined, the Office of the Under Secretary of Defense (2004) reported the loss rate for the Predator at 32, the Pioneer at 334, and the Hunter at 55 (all for much less than 100,000 flight hours). For comparison purposes, the loss rate per 100,000 flight hours during the same period for the F-16 was three, for General Aviation it was one, and for large airlines it was 0.01. Similar figures hold true for non-military UAS as well; the accident rate for UAS flown by Customs and Border Protection (CBP) was recently reported as 52.7 accidents per 100,000 flight hours (Kalinowski, 2010).

As Lacher, Zeitlin, Maroney, Markin, Ludwig, and Boyd (2010) pointed out, "The fundamental difference between manned aviation and unmanned aviation is that the pilot is not physically on-board the unmanned aircraft (p.1)." This simple – and obvious – fact makes it easy to forget that while an UAS does not include a human aboard the aircraft, a UAS is, in fact, a complex system run by a team, whose members have clearly differentiated and interdependent tasks such as Air Vehicle Operator, Payload Operator, and Mission Planner. As a result, an UAS presents the usual coordination challegnes of teamwork, workload, and situation awareness. In addition, there are several human factor challenges unique to UAS. As McCarley and Wickens (2005) pointed out:

> UAV flight presents human factors challenges different from and in some ways greater than those of manned flight. These arise primarily from the fact that operator and aircraft are not co-located. As discussed in more detail below, the separation of operator and vehicle imposes a number of barriers to optimum human performance, including loss of sensory cues valuable for flight control, delays in control and communications loops, and difficulty in scanning the visual environment surrounding the vehicle. (p. 1)

The operator and the aircraft are not the only distributed components of the UAS system. Advances in technology have made it ever more likely that an UAS team - in both military and civilian applications - may be distributed, rather than co-located, as well. An extensive body of research has indicated that such distributed teams often have team processes, especially in the areas of communication and coordination that differ from those experienced by co located teams (Kiekel, Gorman, & Cooke, 2004, Rapp & Mathieu, 2007; Reynolds & Brannick, 2009; Schiller & Mandviwalla, 2007; Stone & Posey, 2008). We therefore suggest that team coordination may be one of the largest human factors concerns for a UAS system, and bolster our argument with a brief review of team coordination and how distribution impacts that process. We then provide evidence from the literature which suggests that coordination plays a critical role in UAS accidents. We conclude with some prescriptions for improving coordination in UAS teams.

Team Coordination

A team is a type of group characterized by differentiated tasks and high levels of interdependence (Mathieu, Heffner, Goodwin, Salas, & Cannon-Bowers, 2000). This interdependence is what Bell and Kozlowski (2002) called *intensive interdependence*, in which team members must "diagnose, problem solve, and/or collaborate simultaneously as a team to accomplish their task (p 18-19)." Teamwork represents how *well* the team members coordinate the interdependent components of performance (Salas, Cooke, & Rosen, 2008). Coordination, or making sure that the right thing happens at the right time, may be one of the most critical aspects of teamwork.

Coordination in Distributed Teams

With reference to teams, *distributed* means geographically, organizationally, or temporally dispersed. Therefore a distributed team (DT) is a group of people with clearly specified roles working interdependently on a common goal, using use some form of computer technology to coordinate at least part of their work. This computer mediated communication (CMC) impacts all of the team processes. The focus during what Marks, Mathieu, and Zaccaro (2001) called the *Transition Process* is on planning, mission analysis, goal specification and strategy formulation. For a DT, a lack of shared context and shared knowledge makes this stage difficult.

During the *Action Process*, the focus is on goal accomplishment through activities such as monitoring progress, sharing knowledge, decision making, communication, and coordination (Marks, Mathieu, & Zaccaro, 2001). In a distributed team, the time delays in sending feedback, the lack of a common frame of reference, the lack of non-verbal feedback, and lack of trust all make coordination difficult (Driskell, Radtke, & Sales, 2003; Hambley, O'Neil, & Kline, 2007; Powell, Piccolo, & Ives 2004; Reynolds & Brannick, 2009).

`Why Coordination is an Issue in UAS

In 1996, the Air Force Scientific Advisory Board identified the human/system interface as the greatest deficiency in UAS designs (Williams, 2006). Other research also supports the idea that human factors are a major concern in UAS. Asim, Ehsan, and Rafique (2010) examined a sample of 56 UAS accidents, and found that human factors were a contributing cause in 32% of them, while Williams (2004), in an analysis of 74 accidents, found that the percentage of accidents attributable to human factors varied across platforms, with 21% of accidents with the Shadow attributable to human error, and 67% with the Predator. Manning, Rash, LeDuc, Noback, and McKeon (2004) investigated the role of human error in U.S. Army UAV accidents and found that human error was present in 32%.of the reported accidents, and, the authors noted that the U.S. Army attributed the lack of good crew coordination as a causal factor.

Crew coordination is made difficult in UAS due to limited bandwidth, and volume of information transmitted (Mouloua, Gilson, Kring, and Hancock, 2001; Van Erp, 2000). One area that appears to be critical in a UAS are the demands placed on coordination during task switching and handoffs between vehicles, payloads, missions, targets, and crew (Fern & Shively, 2011; McCarley & Wickens 2005). Similar findings were reported in a cognitive task analysis of UAS piloting, in which the authors noted that two major concerns were: 1) the competing demands for attention, and 2) a broken or compromised control loop, such as one caused by latency which affects pilot communications, or even a totally lost datalink (Neville, Blickensderfer, Luxion, Kaste, & Archer, 2012).

Possible Solutions to UAV Coordination Issues

Possible solutions for these coordination issues come from a variety of sources: 1) traditions human resource practices such as selection and training, 2) lessons learned from distributed team research, and 3) UAS technology developments.

Human Resource Management. Traditional human resource management practices such as task analysis and training represent one avenue for improving UAS team coordination. Neville, Blickensderfer, Luxion, Kaste, and Archer (2012), as a result of their cognitive task analysis, suggested that the boundaries and responsibilities in the relationship between UAS mission and piloting work need to be clarified, as conflict between mission priorities and piloting responsibilities was a concern. Adams, Humphrey, Goodrich, Cooper, Morse, Engh, and Rasmussen (2009) also used cognitive task analysis to clarify the roles and responsibilities in Wilderness search and rescue mini-UAVs, after having discovered that there were severe coordination deficiencies between the UAS and ground search resources.

One option for training is, of course, a modified form of Crew Resource Management (CRM). Sharma and Chakravarti (2005) noted that "It is prudent to plan CRM training for UAV operators as well. The sole aim of the training shall be to resolve the inherent problems of integrating a collection of technically proficient individuals into an effective team for all situations (p. 36)." Other methods of training could be useful as well. Salas, Nichols, and Driskell (2007) performed a meta analysis of team training interventions, and found a significant tendency for team training to lead to an increase in performance, with the most effective training being that which focused on coordination and adaptation.

Lessons learned from DT. Research indicates that process and performance in a distributed team is helped by a well-defined task structure, goal setting, clearly de ning roles and responsibilities, setting milestones, and agreeing on communication media and frequency (Gibson & Gibbs, 2006; Maynard, Mathieu, Rapp, & Gilson, 2012; Staples & Webster, 2008; Timmerman & Scott, 2006; Walther & Bunz, 2005). Technology focusing on teamwork rather than on flight may be of use as well; a well-designed user interface increases participation, trust, and cooperation, while easy to interpret awareness displays containing information about a remote collaborator's workload lead to communication attempts that are less disruptive, reduce workload, and increase team performance (Chang & Lim, 2006; Dabbish & Kraut, 2008; Strang, et al., 2011). Rusman, Bruggen, Cörvers, Sloep, and Koper (2009) evaluated the effectiveness of a standardized profile and found that the profile helped team members to form an impression of each other during the early stages of a team project.

Although DeLuca, Gasson, and Kock (2006) noted that members of DTs adapted their communication to low richness media by being more precise, concrete, concise, and complete, Belanger and Watson-Manheim (2006) found that DT members preferred using different media for different goals. This suggests that it may be helpful to vary the technology used by the team depending on the task; for example video conferencing during briefing and debriefing, synchronous communication during missions, and asynchronous when not on a mission.

UAS technology. As Williams (2006) pointed out, until recently, most displays have focused on flight, rather than coordination. Research focused on improving communication technology in UAS includes research on airspace display formats for both pilots and camera operators, as well as displays to reduce operator workload during handoffs (Draper, Geiselman, Lu, Roe, & Haas, 2000; Fern, & Shively, 2011). Van Breda, Jansen, and Veltman (2005) have been examining graphic overlays, ecological interface design, head-coupled control, and the use of prediction techniques to help compensate for image degradations. Dixon, Wickens, and Chang (2005) examined the effect of auditory autoalert and an autopilot on: (a) mission completion, (b) target search, and (c) systems monitoring, and found that both systems improved overall performance by reducing task interference and alleviating workload.

Conclusion

Coordination, or making sure that the right thing happens at the right time, may be one of the most critical aspects of teamwork. For a UAS, a number of factors make coordination difficult: 1) distribution, 2) lack of shared context and shared knowledge, 3) time delays in sending feedback, 4) lack of non-verbal feedback, 5) limited bandwidth, and 6) the sheer volume of information transmitted. These difficulties become particularly salient during high workload situations such as task switching and handoffs between vehicles, payloads, missions, targets, and crew. Possible solutions for these coordination issues come from a variety of sources: 1) traditions human resource practices, 2) lessons learned from distributed team research, and 3) UAS technology developments.

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