Measuring Shared Mental Models in Unmanned Aircraft Systems

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INTRODUCTION

While an UAS does not include a human crew aboard, UASs are, in fact, complex systems run by large teams. UAS teams routinely use distributed team members to launch and recover the air vehicle, to process and exploit mission data, or to support ground units involved in complex and dynamic operations. Coordination, or making sure that the right things happen at the right time, is therefore critical. In fact, teamwork represents how *well* the team members coordinate the interdependent components of performance (Salas, Cooke, & Rosen, 2008). Because UAS teams are distributed, there may be: 1) limited bandwidth available for communications, 2) the absence of non-verbal cues from teammates, 3) a lack of shared context and shared knowledge; 4) time delays in sending feedback; and 5) lack of trust (McCarley & Wickens 2005; Mouloua, Gilson, Kring, & Hancock, 2001; Powell, Piccolo, & Ives 2004; Reynolds & Brannick, 2009).

The execution of coordinated behaviors is a symptom of team cognition (Fiore & Salas, 2004). A recent meta-analysis by DeChurch and Mesmer-Magnus (2010) found that team cognition had strong relationships to both team process and performance, and similar findings have been reported regarding distributed team effectiveness (Kanawattanachal & Yoo, 2007; Van den Bossche, Gijselaers, Segers, & Kirschner, 2006). One aspect of team cognition, and the focus of this article, is the shared mental model.

BACKGROUND

History of Unmanned Aviation Systems

As early as 425 B.C., humanity was dreaming of unmanned flight. Inventors and engineers from Archytas of Tarantine to Leonardo Da Vinci attempted to create unmanned aircraft. Yet true unmanned aircraft systems (UASs) did not originate until the mid-20th century (Dalamagkidis, Valavanis & Piegl, 2012; Keane & Carr, 2013). The reasons for the delay were three technological hurdles that had to be overcome: 1) remote control; 2) flight stabilization, and 3) autonomous navigation (Newcome, 2004).

The first hurdle was tackled in 1898, when Nikola Tesla demonstrated what he coined "telautomation" at the Electrical Exposition, in which he was able to remotely pilot a boat around a tank of water. Elmer Sperry, who invented the aircraft gyrostabilizer, designed to level the wings of the aircraft in the absence of pilot input, addressed the second hurdle, which was stabilized flight, in 1909 (Newcome, 2004).

Looking for a way to reduce heavy losses sustained by the air forces in World War I, the United Kingdom and the United States began experimenting with unmanned systems capable of flying to a target and exploding. Aviation pioneers such as Kettering, Hewitt, Sperry, and Low found ways to convert traditional aircraft using gyrostabilizer and remote actuation. These early

DOI: 10.4018/978-1-4666-5888-2.ch113

systems, such as *Aerial Target* and *Kettering Bug,* were crude and unable to navigate a pre-programmed flight plan autonomously and therefore not considered fully capable UASs (Keane & Carr, 2013; Newcome, 2004).

Between World War I and World War II, the British Navy, the U.S. Navy, and U.S. Army continued to foster the testing and development of unmanned systems. From 1934-1943, the Fairey aircraft company produced over 400 Fairey *Queen Bees*, a converted De Havilland Tiger Moth controlled by a simple remote control station using a simple rotary dial to command changes in direction, altitude, and speed (Braithwaite, 2012). World War II brought about the German built V-1 rocket. The V-1 used a pulse jet propulsion system and a very crude guidance system that used barometric pressure to maintain altitude, a directional gyro to maintain heading, and an anemometer to calculate distance travelled (Newcome, 2004). Like the Kettering Bug, the V-1 crews would calculate the distance to the target and then pre-program the aircraft (Austin, 2010).

It was not until a few years after World War II when Charles Draper solved the autonomous navigation problem with the invention of inertial navigation systems (Newcome, 2004). With all the technology in place, the stage was set for modern UASs. The Defense Advanced Projects Agency (DARPA) continued to invest in UAS research with the most significant program being the *Amber* UAS. *Amber* was a joint project for the U.S. Navy and DARPA, aimed at creating a medium altitude long endurance UAS (Ehrhard, 2010). In 1995, *Amber's* latest iteration the *Predator* was deployed, and is still in service.

UAS Crews

At the simipilest level, an UAS is comprised of three main elements; the aircraft, the control station and a wireless data link (Federal Aviation Administration, 2013). The control station is the "flight deck" of the system, comprised of various computers, networking equipment, displays and the the UAS crew (Fahlstrom & Gleason, 2012). A typical UAS crew consists of an air vehicle operator responsible for the control and monitoring of the aircraft, and a payload operator responsible for manipulation of the vehicle's remote sensors (McCarley & Wickens, 2005). Operations such as intelligence, surveillance and reconnaissance collect enormous amounts of data that are exploited in near real time by distributed teams of analysts who are viewing payload data and communicating with the crew. Other UAS operations, such as law enforcement, may require the crew to communicate directly with the service customer on the ground. With such diverse and distributed teams, coordination is critical.

Teams and Coordination

A team is a group whose members have clearly differentiated and interdependent tasks. In 1967, James Thompson presented a typology of interdependence: *pooled*, *sequential,* and *reciprocal*. In pooled interdependence, each person makes a discrete contribution to the whole. In *sequential* interdependence, X must act before Y can act. R*eciprocal* interdependence requires X to act so that Y can act, and Y's actions then influences X's next action. Each type of interdependence requires different types of coordination; reciprocal requires mutual adjustment and horizontal communication, sequential uses planning and regular meetings, and pooled is based on standardization, plans and rules.

Bell and Kozlowski (2002) modified Thompson's framework by adding *intensive* interdependence, which is the interdependence that characterizes UASs. In intensive interdependence team members must "diagnose, problem solve, and/or collaborate simultaneously as a team to accomplish their task" (p 18-19). Because the UAS team may be distributed, there are often problems in diagnosis, problem solving, and collaboration.

Coordination can be accomplished by intentional verbal communication, but the ability to coordinate without extensive discussion is important to team success, especially in a distributed environment (Eccles & Tenenbaum, 2004; Reimer, Park, & Hinsz, 2006). Kleinman and Serfaty (1989) called this ability to maintain coordinated functioning without using a great amount of overt communication "implicit coordination." Cannon-Bowers and Bowers (2006) defined implicit coordination as "… adaptive behavior where team members act on pre-existing knowledge about the task and team in order to coordinate (p. 451)." Espinosa, Lerch, and Kraut (2004) are referring to implicit coordination when they discuss "…high-paced contexts like sports competitions and medical emergency rooms in which members act in a highly coordinated fashion

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