Trust in Unmanned Aerial Systems: A Synthetic, Distributed Trust Model

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An integrated unmanned aerial system (UAS) team is composed of multi-tiered partnerships between at least four distributed entities: the vehicle itself, the vehicle operator(s), the military command team, and the ground team. In this team structure, effective communication, information exchange, and situation awareness within and amongst each entity is critical. While miscommunications can be mitigated through current training strategies and vehicle design, trust plays an important role in these interactions. We have constructed a model of integrated team trust. An extension of this model, directed at distributed trust, is shown to be essential for military teams with integrated UAS. Consequently, we demonstrate the importance of calibrating trust within the team, and in particular the human-UAS partnership.

The utilization of unmanned aerial systems (UAS) is increasing due to their demonstrated benefits in extending the capabilities of unaided human operators in multiple operational realms. Here, we use the term UAS to refer to any unmanned aerial vehicle (UAV) or unmanned combat aerial vehicle (UCAV), including all control technology and monitoring systems. While unmanned vehicles carry no human onboard, these systems are controlled (or monitored) by one or more human operator(s). Therefore, human interaction is required to an extent in order to successfully use the UAS. Many different multimodal control interfaces and design guidelines for customization are available (see Oron-Gilad & Minkov, 2010; Chen, Haas, Pillalamarri, & Jacobson, 2006).

**Unmanned Aerial Systems**

UAS should be used when machines provided better sustained attention than a human; there is a lower political and human cost in high-risk environments; and there is an increase in the likelihood for mission success (Unmanned Aircraft Systems Roadmap 2005-2030, 2005). Consequently, these unmanned systems are currently being integrated and used for a range of missions, including reconnaissance and surveillance, tactical strike, force protection (e.g., detection of improvised explosive devices; crowd control), and electronic signals collection (Billings & Durlach, 2008; Cavett, Coker, Jiminez, & Yaacoubi, 2007; Unmanned Aircraft Systems Roadmap 2005-2030, 2005). Due to task diversity, unmanned vehicles, also referred to as assets, are available in a wide range of platforms (e.g., large, small, fixed wing, ducted fan) and capabilities (e.g., ability to carry different payloads, acquire targets, and flight). These systems range from small man-portable micro-aerial vehicles (MAV) to larger self-landing UCAV (for a detailed description of MAV see Billings & Durach, 2008; for Mini Air Vehicles, see Coffey & Montgomery, 2002; and for UAV and UCAV, see Unmanned Aircraft Systems Roadmap 2005-2030, 2005).

Military operations at the platoon level, company level, battalion level, and brigade level each have access to specific assets specific to the tasking required per level (for a detailed description of integration of UASs in the military hierarchy, see Barnes, 2003). The autonomy and capabilities of an asset are designed specifically for a given team and task type (see Table 1). The degree of human intervention necessary in the operation of the asset is primarily determined by its level of autonomy (Adams et al., 2007). As such, UAS operators may act in supervisory and/or teleoperator roles, and multiple operators are often required. For example, a highly automated UAV may require one (or several) operators to interpret information as the UAV flies through predetermined waypoints. Conversely, a teleoperated UAV may require one operator to manually control it, while another operator interprets...
the acquired sensory information (Billings & Durlach, 2008). The operators in both examples can vary in the extent of their geographical separation from the asset, from the ground team to the United States launch site.

Table 1. Examples of unmanned aerial systems: task, flight information, operation, level of automation

<table>
<thead>
<tr>
<th>Asset</th>
<th>Task</th>
<th>Flight Information</th>
<th>Operator</th>
<th>Level of Automation</th>
</tr>
</thead>
<tbody>
<tr>
<td>RQ-11 Raven</td>
<td>Intelligence gathering</td>
<td>1.5 hours, 1,000 ft, 4 lb</td>
<td>Controlled by ground team</td>
<td>Can fly along GPS waypoints or be controlled by ground operator</td>
</tr>
<tr>
<td>RQ-2B Pioneer</td>
<td>Intelligence gathering</td>
<td>5 hours, 12,000 ft, 452 lb</td>
<td>Controlled from launching airfield or ship</td>
<td>Can fly preprogrammed waypoints but is usually controlled by an operator out to a range of 100nm</td>
</tr>
<tr>
<td>RQ-1 Predator</td>
<td>Intelligence gathering</td>
<td>29 hours, 40,000 ft</td>
<td>Remote station or airfield</td>
<td>Directly flown by operating team</td>
</tr>
<tr>
<td>RQ-4A Global Hawk</td>
<td>Intelligence gathering</td>
<td>32 hours, 65,000 ft, 32,250 lb</td>
<td>United States or point of launch (far from recon sight)</td>
<td>Follows a programmed set of waypoints that can be upgraded during operation</td>
</tr>
<tr>
<td>MQ-1: Armed Predator</td>
<td>Tactical Strike</td>
<td>24+ hours, 25,000 ft, 2,250 lb</td>
<td>Control center</td>
<td>Pilot in the loop: Operators at control center would control target designation and firing of weapons.</td>
</tr>
<tr>
<td>MQ-9B: Reaper</td>
<td>Tactical Strike</td>
<td>29 hours, 40,000 ft, 10,500 lb</td>
<td>United States or point of launch (far from recon sight)</td>
<td>Monitored by the ground crew and target selection and firing are controlled by the ground crew.</td>
</tr>
<tr>
<td>X-45</td>
<td>Tactical Strike</td>
<td>7 hours, 35,000 – 40,000 ft, 36,500 lb</td>
<td>United States or point of launch (far from recon sight)</td>
<td>Autonomous takeoff/landing; designated waypoints through a combat zone. Ordinance likely to be GPS guided bombs, allowing for hands-off weapons delivery.</td>
</tr>
</tbody>
</table>


Integrated UAS Team

The UAS asset is currently designated as a tool with programmed tasking to extend the capabilities of the operator. The operator’s extensive tasking can include deployment and retrieval of the asset, monitoring and control of the asset (e.g., navigation, perception and manipulation of remote environments), managing mission and status (e.g., communication, decision-making, monitoring human and robot tasks, coordinating social interaction tasks), and managing camera feeds (Adams et al., 2007; Cavett et al., 2007; Chen et al., 2006). However, the operator-asset
partnership cannot be considered in isolation; the operator works in conjunction with command personnel (responsible for planning and allocating resources), aircraft pilots, other operators (Mouloua et al., 2001), and a ground team (responsible for carrying out actions in the combat zone). Therefore, a team with an integrated asset(s) incorporates a unique, multi-tiered partnership between at least four distributed entities: the asset (e.g., UAV, UCAV), the human operator(s), military command team, and the ground team. Chen and colleagues (2006) have described this partnership as an interdependence as seen through defining the mission and tasks, allocating tasks, two-way feedback between operator and robot, controller input, and analysis of information. Burke and colleagues (2004) discuss three possible relationships between the human team members and the asset: the human-robot ratio (i.e., number of humans assigned to an asset), the spatial relationship (i.e., distance between the human and asset, as well as point-of-view), and the authority relationship (i.e., defining the roles of the team). These relationships can impact the team’s workload, communication, and situation awareness within a mission.

Communication

One of the major issues in the operation of an asset is the proper communication of information across the levels of the integrated UAS team. This communication requires some degree of audio, visual or tactile relay of information from an asset to an operator across an often large geographical distance. Due to the large amount of information that is relayed, it is important to ensure that the information is exchanged efficiently. Yet, different assets have different sensors and relay different types and amounts of information. Some issues related to the transfer of information directly from an asset include the complexity, organization and time lag in communication, as well as the flexibility, adaptability, and cognitive controllability of the bandwidth and frequency (Chen et al., 2006; Unmanned Aircraft Systems Roadmap 2005-2030, 2005; Burke, Murphy, Rogers, Lumelsky, & Scholtz, 2004). Here we are interested in the information flow and distributed communication between team members as it relates to type of task.

According to Adams and colleagues (2007) there are three main paradigms for types of tasks that utilize an UAS integrated team: Information Only, Ground-Led, and UAV-Led. While these task types are specific for search and rescue, they can be extended to other domains. Within the Information Only task, there is no direct partnership between the asset and the ground team. There is a direct flow of information from the asset to operator to commander to ground team. The operators utilize the asset to gather information. This is followed by a command team dispatching the ground team. In the Ground-Led task, the asset follows a ground led search and is used as a support when the ground team loses a trail. The asset can increase the effective field of view and provide increased information to the ground team without corrupting the trail. The UAV-Led task incorporates a direct partnership between the asset and the ground team. The ground team has a direct link to the data from the asset, and both teams provide a target location to the command team. The asset’s path is preselected by waypoints to match the ground team, and can be updated based on collected target information. Communication is very different across these three types of tasks (see Figure 1 for communication links in terms of data flow and commands/requests). Communication in this teaming incorporates data flow as well as commands and requests. Data flow consists of the audio, visual or tactile information that is relayed through the team. Commands and requests require human interpretation of this data. Situation awareness allows the filtering of data at each level of the integrated team.

There are three levels of SA that must be considered at each level of the team: perception, comprehension or understanding, and projection into the future (Endsley, 1995). UAS extend an operator’s SA by increasing the amount of information an operator has access to at both the local (operator station) and remote (asset) environment. In this way, a UAS operator can filter sensory information acquired from the asset, only relaying information vital to the success of the mission to the other members of the team. This process can be hampered by exceeding amounts of information and elevated workload. Therefore, future work is examining how to improving interfaces and automation to assist operators “absorb, assimilate, and track relevant information over time” (Riley, Strater, Chappell, Connors & Endsley, 2010) in order to increase SA at the asset level. Until these design, enhancement in communication between team members can lead to the more accurate interpretation of information and more effective situation awareness (Cavett et al., 2007).
Design and Training

System design and training guidelines continue to lead to the reduction of operator workload and enhanced performance in areas such as communication and situation awareness. A main goal of UAS teams is to reduce operator workload to such a degree that a reduction in the operator-asset ratio will lead to a single operator being able to control multiple assets. In attempting to meet these goals, the asset is moving away from a tool that is an extension of the operator to more of a human-asset partnership. Schulte and Meitinger (2010) refer to this teaming as co-operative control, in which interaction occurs through communication and a shared understanding of the situation. Therefore, critical attention is placed on the design of interfaces, displays, staffing of control stations (Billings & Durach, 2008; Mouloua, Gilson, Kring & Hancock, 2001). Further design of the autonomy and operator interfaces should be intuitive, facilitate control and data interpretation, promote the efficient use of time, have a high tolerance for workload, and span multiple application domains with minimal training requirements (Oron-Gilad & Minkov, 2010; Billings & Durach, 2008; Adams et al, 2007; Burke et al, 2004). Training methods should be systematic, standardized, modular and flexible, with short training for simple tasks and main efforts on mission implementation (Oron-Gilad & Minkov 2010; Billings & Durach, 2008).

Trust

While the design of these unmanned systems, partnered with more systematic and standardized training protocols, are steadily enhancing the assets ability to complement and extend the capabilities of the human team members (e.g., situation awareness, decision making), the inappropriate calibration of trust within a human-robot team can lead to misuse or disuse in the field. A meta-analysis on human-robot trust (see Hancock et al, 2011) has provided support for inclusion of trust as a factor in human-robot teaming ($d = +0.71$), as well as for our three-factor model (see Figure 2) of trust in human-robot teams. From this meta-analysis, we found robot characteristics ($d = +0.67$) to be the presently, primary driving influence of trust in human-robot teams, followed by environmental characteristics ($d = +0.47$) with little influence from human characteristics. These findings suggest that calibration of human-robot trust could occur through specific integration of trust characteristics into the design and training protocols.
**Distributed Trust**

These meta-analytic findings can be directly applied to the integrated UAS team at the operator-asset level. However an extension of this model specific to the multi-tiered partnerships and tasking is necessary. Integration of an asset affects (both directly and indirectly) the task completion and flow of information to the rest of the team. Therefore the application of system based trust (primary-level, secondary-level, tertiary-level, and so forth) is instituted. Primary-level trust can occur for entities that receive direct communication from another entity. Conversely, secondary-level trust may be present among team members across all lines of indirect communication. Tertiary-level trust is a more complex interaction between multiple team members. This distributed trust model only incorporates the notions of the primary-level and secondary-level trust within UAS teams for each type of task (Information Only, Ground-Led, and UAV-Led tasks; see Figure 3). A certain threshold of trust between team members needs to be reached so that effective interactions can occur. Calibration of trust helps to optimize this threshold between levels of under-trust (disuse) and over-trust (misuse). Total system trust can then be determined through the summation of the individual trust relationships (e.g., primary, secondary, tertiary level trust) between team members within a given task.

![Figure 3. Primary and secondary trust links among a multi-tiered team in three types of tasks.](image)

The calibration of trust between team members in a UAS teaming environment is important to consider in tandem with team communication. Trust calibration refers to match between an individual’s perception of the robot and the robot’s actual capabilities and performance (Hancock, Billings, & Oleson, 2011; Lee & See, 2004). Based on the above identified flow of communication and trust, we suggest that the calibration of trust at the operator-asset level will improve this direct interaction, as well as interaction, trust, and communication across the other team levels. The reasoning for calibration of trust at this level takes into account both the initial level of trust in an asset along with the high operator workload in this relationship. Therefore, ensuring appropriate trust at the operator-asset level can, in part, assist with issues in operator workload and situation awareness. Reduction in workload and an increase in situation awareness can, in turn, increase the efficiency of data information flow between the operator-asset and the ground team. In this way, trust in the operator-asset relationship trickles down and affects communication at these other levels.

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