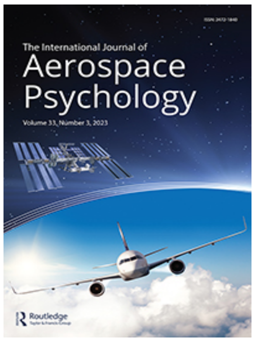

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TRUE EXPERIMENTS

Team Performance in Air Combat: A Teamwork Perspective

Heikki Mansikka [a,b], Kai Virtanen[a,b], Don Harris [c], and Juha Järvinen[d]

[a]Department of Mathematics and Systems Analysis, Aalto University, Helsinki, Finland; [b]Department of Military Technology, Finnish National Defence University, Helsinki, Finland; [c]Faculty of Engineering, Environment and Computing, Coventry University, Coventry, UK; [d]Finnish Air Force, Jyväskylä, Finland

ABSTRACT

Objective: The objective of this paper is to describe a model combining taskwork and teamwork of a single-seat fighter aircraft team, or flight, during its performance episode.

Background: In air combat, evaluations of team performance have focused on task performance. However, both teamwork and taskwork are required for high performance output. Attempts to address taskwork and teamwork in single-seat fighter aircraft flights have mainly settled for adopting existing models of teamwork to flights. As such, they have overlooked the unique nature of teamwork in air combat.

Method: Existing models of teamwork and taskwork are reviewed and a flight's tactical decision-making is described as an input-process-output model. A model combining flight's teamwork, taskwork, situation awareness and transactive memory is conceptualized and operation of the model is illustrated with a case study. In the case study, the model is used to provide an alternative explanation for an air combat accident.

Results: The model bridges the gap between the well-established concepts of teamwork and the unique nature of air combat. It rationalizes how the mission essential competencies, situation awareness and transactive memory interact with each other, and how they impact the flight's performance output.

Conclusions: The model helps scholars and practitioners in identifying the connection between the flight's performance output and the underlying processes even when cause and effect are not adjacent in either time or space.

Introduction

Teams engage in teamwork and taskwork, with both required for high performance output (McIntyre & Salas, 1995; Salas et al., 2004). In simple terms, taskwork is about what the team does, whereas teamwork is about how the team does it (Marks et al., 2001; Salas, Stagl et al., 2007). Teamwork has been widely studied in various domains (e.g., Cotard & Michinov, 2018; Gao et al., 2015; Moon et al., 2020; Rafferty et al., 2010; She et al., 2019; Stanton & Roberts, 2020; Stevens et al., 2021; Wang et al., 2020). Despite the rich literature about teamwork, few studies describe the concept of teamwork in the context of air combat. Erlandsson et al. (2010) specifically identified a lack of understanding concerning teamwork among fighter pilots.

CONTACT Heikki Mansikka heikki.mansikka@aalto.fi Department of Mathematics and Systems Analysis, Aalto University, P.O. Box 80, Tampere FI-33901, Finland

To understand team effectiveness a model specific to the context and technology is required (Goodman et al., 1987). A model simply describing group effectiveness in general will not suffice. The findings from the extensive literature regarding teamwork in general are often difficult to apply in practice (Salas, 2008; Tannenbaum et al., 2012; Wildman et al., 2012) if context and tasks are not specified and described in sufficient detail. For example, challenges such as time pressure, workload, complexity and uncertainty (all elements characterizing air combat) are factors that if unspecified and undescribed, will detract from developing an understanding of contextual effects (Tannenbaum et al., 2012).

Almost all air combat missions are conducted as a team, i.e., flights. Air combat is dynamic and takes place in a complex task environment unlike any other: Without teamwork, single seat fighter aircraft operations would be ineffective and hazardous (Hierl et al., 2012). Mansikka et al. (2020) described team performance in air combat training from the taskwork perspective, but relatively little is known about how teamwork affect team performance in air combat training, and how teamwork and taskwork interact in this context. Pilots engaged in air combat and air combat training must address unique problems in a hostile, dynamic and time-critical environment where the best solution is not always obvious (Bennett Jr et al., 2002). Pilots must be able to operate as a cohesive team in this seemingly chaotic and unpredictable activity (Mansikka et al., 2019b; Rajabally et al., 2009).

Ohlander et al. (2019) and Tsifetakis and Kontogiannis (2019) have described the teamwork of fighter pilots by adapting existing models of teamwork, such as 'The big 5' (Salas et al., 2005), Non-Technical Skills (NTS; Flin et al., 2003; O'Connor et al., 2002) or Crew Resource Management (CRM; Helmreich et al., 1999). However, as O'Connor et al. (2012) point out, any teamwork model which overlooks the unique nature of fighter operations is unlikely to gain pilot acceptance. This paper explicitly addresses the unique nature of single seat fighter operations by combining flight's teamwork and taskwork into a single holistic performance model.

Regarding the development of the performance model, the task- and teamwork mechanisms and constructs relevant to air combat are initially described. Air combat is conceptualized in the model which explains the interaction between the task- and teamwork, and how these contribute to team performance in air combat. This paper embraces the unique nature of single-seat fighter aircraft operations and appreciates the boundaries of teamwork and taskwork. The model is illustrated with examples of its implementation in typical air combat (training) engagements. The paper concludes with a case study drawn from an accident report involving two F-16C fighter aircraft from the United States Air Force (USAF) to demonstrate the consequences of teamwork in air combat training.

Task- and Teamwork Mechanisms and Constructs

Taskwork describes activities linked directly to team's performance output and is often described in the form of an 'Input – Process – Output' (IPO) model (Hackman, 1987; Kozlowski et al., 1999; Mansikka et al., 2019a; McGrath, 1984). Where taskwork deals with what teams do, the literature on teamwork mainly concentrates on team processes and emergent states (especially the cognitive ones) and explains how and why inputs influence team effectiveness and outcomes (Ilgen et al., 2005; Kozlowski & Ilgen, 2006; Marks et al., 2001). Team processes refer to the functions performed by team members to accomplish a team's goals; the cognitive emergent states are cognitive properties of the team, such as team situation awareness (TSA; Endsley, 1995; Helmreich et al., 1999) and transactive memory (Marks et al., 2001). Although the emergent states are not processes *per se*, they evolve based on team members' interaction within the process phase of the IPO model. They underpin team processes and performance outputs, and eventually inputs (for example, by directing the search for new information (Li & Harris, 2007)) once a new performance episode begins (Marks et al., 2001). There is an abundance of teamwork models suggesting how different competencies affect teamwork (see, e.g., LePine et al., 2008; Salas et al., 2005; Shuffler et al., 2012). Determining the similarities and differences between the different competencies is complicated by the interchangeable use of terms. However, the most prominent teamwork models have more in common than their terminology suggests, and many of the terms can be mapped onto a few key team competencies, or team skills, knowledge and attitudes (Salas et al., 2009).

For the most part, team competencies are measurable descriptions of effective management behaviors of team- and taskwork processes. Team competencies are considered to be independent from the team's immediate task environment and thus support effective team functioning even in novel situations (C.M. Colegrove & Bennett, 2006). Taskwork competencies are task specific, whereas teamwork competencies can be either task generic or task specific (Cannon-Bowers et al., 1995). A variety of teamwork-related terms used in different IPO-models can be used to describe three key competencies, i.e., communication, coordination, and cooperation, and two cognitive emergent states, i.e., transactive memory and TSA (DeChurch & Mesmer-Magnus, 2010; Rafferty et al., 2010; Wilson et al., 2007).

The cognitive emergent states are the primary explanatory variables mediating or moderating the relationship between inputs and outputs within the IPO process (Ilgen et al., 2005; Mathieu et al., 2008; Rico et al., 2010). They are relatively dynamic, collective-level cognitive characteristics that vary as a function of team context, inputs, processes and outputs (Marks et al., 2001). The cognitive emergent states include two related constructs of shared cognition: TSA and transactive memory. TSA has occasionally been interchangeably referred to as shared knowledge, team mental model, team situation model and shared mental model (Salas et al., 2005). TSA specifically describes a team's shared and organized understanding of relevant knowledge about the team itself and the system it is interacting with (Cannon-Bowers et al., 1993; Klimoski & Mohammed, 1994). Transactive memory is closely related to TSA and describes the knowledge of information distribution within a team, i.e., an awareness of who knows what (DeChurch & Mesmer-Magnus, 2010; Kozlowski & Ilgen, 2006) – also referred to as team knowledge (McIntyre & Dickinson, 1992).

Within the process phase of the IPO-model, cooperation, coordination and communication are the top-level teamwork competencies contributing to shared cognition and effective team functioning (Wilson et al., 2007). The cooperation competency addresses the social processes and states within a team, such as team orientation (McIntyre & Dickinson, 1992; Salas et al., 2005; Wilson et al., 2007), conflict management (Marks et al., 2001); mutual trust (Salas et al., 2005; Wilson et al., 2007), affect management (Marks et al., 2001; LePine et al., 2005), cohesion (Fleishman & Zaccaro, 1992; Wilson et al., 2007) and group synergy (Hackman, 1987). Cooperation is a result of team development which unfolds over time as the team matures. Team development is based on the feedback a team receives regarding its performance as it transitions from one performance episode to another (Mathieu et al., 2008). Performance episodes are distinguishable periods of time over which a teams' goal directed activity accrues and feedback is available (Mathieu & Button, 1992; Zaheer et al., 1999). However, teams' cooperation characteristics take time to develop (Kozlowski & Klein, 2000; Mathieu et al., 2008). In the air combat context, the flights do not always stay together long enough for such maturation to take place.

Unlike cooperation, coordination involves a temporal component and does not extend across performance episodes. Coordination is about the synchronization of the team members' performance requirements to reach successfully the team's tasks and objectives (Cannon-Bowers et al., 1995) and involves activities such as mutual performance monitoring (Salas et al., 2005; Wilson et al., 2007), backup behavior (Marks et al., 2001; McIntyre & Dickinson, 1992; Salas et al., 2005; Wilson et al., 2007) and adaptability (Salas et al., 2005). For coordination to be effective, the flight must gain and maintain TSA about the team members, systems and processes used for the task (Marks et al., 2001; Le Pine et al., 2005), and manage the progress of the task (LePine et al., 2008; Marks et al., 2001; Salas et al., 2005). In addition, effective coordination enables identification of performance deficiencies and potential backup behaviors (McIntyre & Dickinson, 1992; Wilson et al., 2007). Coordination can be either explicit or implicit (Converse et al., 1991; Lim & Klein, 2006). Implicit coordination is promoted by transactive memory and TSA and enables the team members to anticipate each other's actions and needs without having to communicate or plan the activity (Cannon-Bowers et al., 1993; Langan-Fox et al., 2004; Rico et al., 2010). Explicit coordination relies on communication and is another way for the team to achieve the necessary sequencing and integration of team members' activities.

Communication allows for data and information to circulate between the team members and the team's systems. In its simplest form, communication is about exchanging information between a sender and a receiver (Wilson et al., 2007). An effective way to transfer information is to utilize closed-loop communication, which involves sending the information, acknowledging its receipt, and confirming the correct interpretation of the sent information (Bowers et al., 1998; McIntyre & Salas, 1995; Salas et al., 2005; Wilson et al., 2007). In summary, TSA and communication are essentially two different, complementary means of achieving coordination.

While teams of single-seat fighter aircraft engaged in air combat share some of the general teamwork characteristics discussed above, the nature of such teams is unlikely to be understood simply by applying a generic teamwork model. Therefore, in the next section air combat is described using a novel theoretical performance model illustrating the interactions between taskwork, the most relevant teamwork competencies and the underpinning cognitive emergent states in fighter aircraft teams. As the model concentrates only on the most relevant aspects of teamwork and taskwork, it is by no means all-inclusive. It will, however, help in understanding how taskwork and these aspects of teamwork contribute to the performance output of single-seat fighter aircraft teams.

Model of Teamwork and Taskwork in Air Combat

A variety of models and frameworks have been developed to explain the association between the processes, emergent states and competencies within a team (Salas, Stagl et al., 2007). Previous frameworks that have specifically addressed taskwork and teamwork of fighter aircraft flights have had varying success in describing the unique demands of this situation. The Mission Essential Competencies (MECs) developed by C. M. Colegrove and Alliger (2002); C. M. Colegrove and Bennett (2006) focused mainly on fighter pilots' taskwork and sought to identify the pilot's training requirements. As such, the MECs address teamwork processes, cognitive emergent states and team competencies only indirectly.

To continue and extend the work of Ohlander et al. (2019), Tsifetakis and Kontogiannis (2019), and Mansikka et al. (2020), a holistic performance model of a flight's teamwork and taskwork during a performance episode, i.e., during a single air combat (training) mission, is conceptualized in Figure 1. Similar to Mansikka et al. (2020), the model considers air combat as a system with which the flight interacts. From the perspective of classic system models, team performance within the proposed model is comprised of input, process and output phases (Mansikka et al., 2019a; McGrath, 1984; Steiner, 1972). From the perspective of human information processing, the process phase is further divided into decision-making, response selection and response execution stages (Wickens, 1991, 2002). The opening stage of human information processing, i.e., perception, lies within the input phase. Finally, from the perspective of competencies and cognitive emergent states, the flight manages its teamwork by utilizing the key competencies and cognitive emergent states discussed above. The cooperation competency is not included in the model. The model as described is limited to a single performance episode and the development and impact of cooperation extends across several performance episodes. At the same time, the life cycle of a flight may not exceed beyond a single performance episode. Pilots may also be tasked to operate as a flight with previously unknown colleagues with little or no notice. It was therefore considered arbitrary to include cooperation and the associated factors as elements within this model. Furthermore, the flight manages an air combat mission with task-specific taskwork competencies. These taskwork competencies are illustrated in Figure 1. These mirror the taskwork competencies defined for single-seat fighter operations by Alliger et al. (2013). The same competencies have been used to develop fighter pilots' training programs

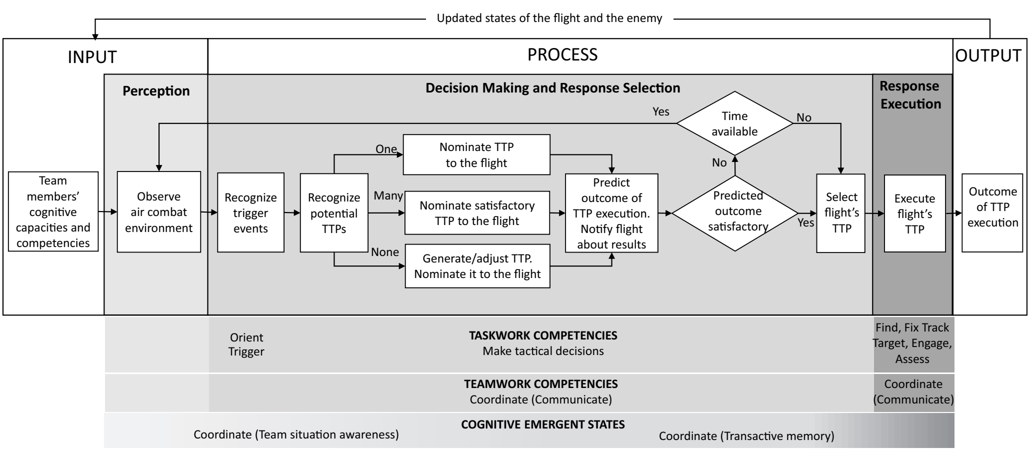

Figure 1. Model of flight's teamwork and taskwork in an air combat performance episode. For the sake of clarity, the taskwork competencies mentioned in the Figure only cover the flight's kill chain. However, the flight has also a corresponding live chain with associated competencies.

in the United States Air Force (Symons et al., 2006) and in the Royal Netherlands Air Force (Van der Pal et al., 2009).

The inputs for the process phase are comprised of the flight members' cognitive and perceptual capabilities and competencies (e.g., tactical knowledge held in pilots' long-term memories), the cognitive emergent states of the flight (TSA and transactive memory, which will serve to direct their attention), and the products of the perception stage. During the perception stage, the flight members survey the air combat environment using their on-board sensors, tactical datalink, visual observations and received radio transmissions. As the pilots communicate their observations about, e.g., positions and activity of the enemy aircraft, they use the orient taskwork competency to build and maintain both transactive memory and TSA levels 1–3 (Endsley, 1995; Mansikka et al., 2020). In its simplest form, the pilots orient by sharing their observations (TSA level 1). In addition, they strive to orient by disseminating, exchanging and comparing their knowledge of its meaning (TSA level 2) and the future states (TSA level 3) of those observations. The orient competency has its roots in the Observe-Orient-Decide-Act- (OODA) loop (see, e.g., Bryant, 2006; Endsley & Jones, 1997) and is essentially a synonym for situation assessment (Salmon et al., 2008). It has been argued that the process of situation assessment is a precursor to situation awareness, which is itself the precursor to decision-making (Prince & Salas, 1997). Based on the flight's transactive memory and TSA, the pilots utilize a trigger competency to recognize events which require decision-making and response selection activities (Symons et al., 2006). A radar detection of an enemy aircraft arriving at a certain range from the flight, a visual detection of a surface-to-air missile launch or a radio call of an unidentified aircraft entering into a no-fly zone are typical events which trigger tactical decision-making. In a sense, observations, orient and trigger competencies and the cognitive emergent states form a fast paced perceptual cycle (Neisser, 1976; Plant & Stanton, 2015) which the flight maintains as it prepares to initiate a process of tactical decision-making.

TSA levels 1–3 are critical enablers for the decision-making and response selection stage, where the flight uses the tactical decision-making competency to select appropriate tactics, techniques and procedures (TTPs) for the situation at hand. TTPs are a set of tactical rules and rule values that, when adhered to, allow the flight to orchestrate the flight members' actions, creating order in an otherwise chaotic activity (Mansikka et al., 2019a, 2019b; Rajabally et al., 2009). For example, an unidentified aircraft detected at a certain range could result in a flight leader triggering a VID (Visual Identification) TTP, which dictates what kind of geometry and formation the flight will use to safely intercept the detected aircraft. Alternatively, a missile launch warning received by one of the flight members could trigger a defensive TTP for the whole flight. The TTP selection is based upon a flight's TSA and transactive memory (i.e. implicit coordination) or communication (i.e. explicit coordination).

The flight's TTP selection decisions in air combat epitomize a naturalistic decision-making process within a complex sociotechnical system, in which pilots must make critical decisions in near real-time (Plant & Stanton, 2015). It is characterized by ill-defined goals, uncertainty, dynamic and continually changing conditions, and experienced decision makers (Klein, 1989; Plant & Stanton, 2015). For the flight, each air combat scenario presents unique problems where the best TTP is not obvious, and where the flight typically does not have adequate time to analyze the situation and search for the best offensive or defensive TTP (Bennett Jr et al., 2002; Klein, 1993). Instead, to keep up with the operational tempo, the flight tends to settle on a satisfactory TTP for the problem at hand (a process of satisficing) rather than the best solution (Klein, 1993; Li & Harris, 2007). The best parameters for a specific missile launch situation could be to climb to 32 735 feet and to accelerate to Mach 1.15. But instead of making time consuming reasoning about the best parameters, the flight may elect to use a satisfactory rule of thumb and to climb to 30 000 feet and to launch the missile at Mach 1.0. As reflected in the proposed model, the flight's tactical decision-making can be best understood as an application of a recognition primed decision-making (RPD) model (Klein, 1989; Klein et al., 1986).

As illustrated in Figure 1, the decision-making and response selection stages within the process phase are essentially about the TTP selection decision. As this stage is initiated, the flight attempts to recognize the repertoire of possible tactical decision alternatives, or TTPs. It is possible that a flight recognizes none, one or many. If not even a single feasible TTP is recognized, a complex decision-making strategy must be applied (Klein, 1993). This means that a flight must adjust an existing TTP or generate a new one such that the resulting TTP satisfies the task demands. For example, a flight may face unanticipated enemy tactics, against which it has no countertactics available as a quick, textbook TTP. As some kind of TTP decision is still required, the flight must modify an existing TTP for this novel situation. In a worst case scenario, not a single TTP is suitable for the situation and the flight leader must generate and communicate an ad-hoc TTP to all flight members while the flight actively manages the situation. In all other cases, the flight matches its TSA with an existing TTP and nominates that TTP. Before the flight selects a TTP, it predicts the outcome of its execution by utilizing TSA level 3 for a forward looking mental simulation (Klein, 1993). If the predicted outcome is not satisfactory and time permits, the flight updates its TSA to support further, revised decision-making. Otherwise, the flight selects the TTP and executes it in the response execution stage. From the perspective of taskwork, the TTP selection decision is about utilizing the tactical decision-making competency. Effective decision-making relies upon transactive memory and TSA, with communication acting as a slower and more error prone backup mechanism (Mansikka et al., 2023).

The TTP selection is followed by response execution, which is the last stage within the process phase (see Figure 1). The response execution stage involves the management of two parallel processes, i.e., kill and live chains. The management of kill chain involves the following taskwork competencies: Find, Fix, Track, Target, Engage, and Assess. In a modern fighter aircraft, finding and fixing occur simultaneously and result in locating the enemy with the flight's sensors, typically with an on-board radar. Once the enemy is found, it is tracked with a radar or with an electro-optical sensor such that weapons can be assigned against it. Next, the enemy is targeted, meaning that the responsibility to manage any follow-on actions against it is assigned to a flight member, thereby avoiding multiple flight members unintendingly engaging the same enemy. In simple terms, engaging means launching weapons against the targeted enemy. From the weapon launch to a point where it should impact the enemy, the weapon's effectiveness is assessed. If the weapon effect is determined to be unsatisfactory, a flight may decide to reengage the same target. The enemy aircraft also have kill chains of their own, which describe their progress in intercepting the flight. The management of the flight's live chain is about denying the progress of the enemy's kill chains. Therefore, the management of the live chain involves the following taskwork competencies: Deny Find, Deny Fix, Deny Track, Deny Target, Deny Engage, and Deny Assess. A flight can deny find, fix, track, target and assess by using passive or active countermeasures, such a chaff or electronic jamming. The simplest way of denying an engagement is to maneuver such that the friendly aircraft stays geometrically outside the enemy's permittable weapon launch region. For the sake of clarity, only the kill chain competencies are listed in Figure 1. For a more detailed description of the kill and live chains, see Mansikka et al. (2020), Joint Chief of Staff (2013), and Symons et al. (2006).

By adhering to a TTP, the flight exercises the coordination teamwork competency. Effective TTP execution relies on the emergent cognitive states of TSA and transactive memory, and manifests itself as implicit coordination (Converse et al., 1991; Lim & Klein, 2006). If, however, implicit coordination fails, the flight can and must rely on the less effective communication teamwork competency to manage the flight members' interrelated tasks during the TTP execution (Mansikka et al., 2023). Finally, the outcome of the TTP execution results in changes in the states of both the friendly flight and the enemy aircraft. When these updated states are observed and disseminated across the flight, TSA and transactive memory are updated and a new iteration of taskwork may be triggered.

To keep up with the tempo of air combat, the flight's tactical decision-making must be fast paced. This is achieved by partitioning complex decisions into a sequence of simple, quick decisions. For example, when a flight has committed to a TTP, it constantly monitors its progress. In a modern fighter aircraft, the flight members automatically receive each other's positions and kill-chain progressions via datalink. If the TTP progresses as planned, it may seem that only a few, if any, decisions are required from the flight. In fact, the case is just the opposite. It is typical that the seemingly inactive phases of air combat involve fast paced, sequenced decisions about whether it is still sensible to proceed with the selected TTP (see upper feedback loop in Figure 1). Even though the model has many steps, even the fastest tactical decision-making follows the process described in it.

The model bridges the gap between the well-established concepts of teamwork and the unique nature of air combat fighter operations. More specifically, it rationalizes how the essential competencies and cognitive emergent states interact with each other, and how they impact the flight's performance. By doing so, the proposed model can help in identifying the connection between the flight's performance and the underlying processes – even when the cause and effect would not be adjacent in either time or space. While such a process-oriented approach can reveal both the failures and successes of teamwork, the latter ones are rarely documented: successful missions that proceed as planned are rarely the subject of extensive case-studies. For successes, analysis tends to be restricted to post-flight debriefs.

Goodman et al. (1987) suggested that to understand team performance it is essential to develop a model specific to the context and technology. Furthermore, it was previously noted that findings from the literature were often difficult to apply in a practical context (Salas, 2008; Tannenbaum et al., 2012; Wildman et al., 2012). The next section illustrates the operation of the proposed model using an accident report involving two USAF F-16C fighter aircraft flying an air combat training mission. It should be stressed that the model introduced in this paper is equally suitable for an investigation of both failures and successes of teamwork in training and real air combat missions.

Case Study

Two F-16C fighter aircraft collided mid-air during an air combat exercise near Louisville, Georgia on June 7, 2016. First, a brief description of the sequence of events leading to the accident is provided, followed by a summary of key conclusions listed in the USAF Accident

Investigation Board (AIB) report (USAF, 2018). The conclusions are then discussed in the light of the model described in Figure 1.

A flight of four F-16C aircraft (call signs Mace 31–34) was flying an air combat training mission against two F-16C aircraft just after twilight. Whenever the separation between Mace 33 and Mace 34 was less than 3 nautical miles (nm), Mace 34 was tasked to maintain a tactical formation by visually observing Mace 33. When the separation exceeded 3 nm, Mace 34 was to maintain formation and to deconflict from Mace 33 by using an air-to-air Tactical Air Navigation (TACAN) system and the aircraft's fire control radar (FCR). As an additional deconfliction method, Mace 33 and Mace 34 were assigned sanctuary altitudes, separated by 1,000 feet. Mace 33 and Mace 34 had no datalink available. The datalink would have provided pilots with data such as information about the friendly aircraft locations.

While conducting an attack, Mace 33 and Mace 34 executed maneuvers which resulted in their separation exceeding 3 nm and Mace 34 losing visual contact of Mace 33. Mace 34 informed Mace 33 about losing a visual and asked Mace 33 to launch a flare. Following Mace 34′s visual acquisition of the flare, the attack was continued with Mace 34 slightly over 3 nm behind Mace 33. Soon after, Mace 34 reported a fuel state that required termination of tactical maneuvering and return to base. Mace 33 acknowledged this but started a tactical left turn without informing Mace 34 about the maneuver. Mace 34 repeatedly attempted to obtain a boresight FCR lock on Mace 33 but was not successful. Boresight is a within-visual-range air combat FCR mode, not suitable for the tactical beyond-visual-range task they were assigned to fly. At that point, the lateral separation between the aircraft was 3.8 nm and their vertical separation had reduced to 360 feet. Once Mace 33 had finished the turn, Mace 34 wrongly perceived that Mace 33 was still turning and flying away from Mace 34 – when in fact the two aircraft were approaching head-on. Approximately five seconds before the collision, both Mace 33 and Mace 34 obtained a boresight FCR lock of each other. Despite significant control inputs by both pilots, Mace 33 and Mace 34 collided. Both pilots ejected suffering minor injuries. Both aircraft were destroyed after impacting the ground.

AIB report concluded that the mishap was caused by the Mace 34′s failure to deconflict from Mace 33. Two contributing factors were found. First, Mace 33 did not terminate tactical maneuvering once the Mace 34′s fuel state dictated so. Second, both Mace 33 and Mace 34 overly relied on visual cues to judge the flight parameters. The human factors analysis within the accident investigation report concluded that according to the taxonomy of the Department of Defense's Human Factors Analysis and Classification System (Department of Defense, 2005), the human performance aspects associated with the mishap included inaccurate expectation, fixation, failure to prioritize task adequately, failure to effectively communicate, and complacency.

In the light of the model described in Figure 1, the conclusions about the causes of the mishap are somewhat different. After Mace 34 lost visual contact of Mace 33, the TSA started to deteriorate. Mace 33′s awareness about Mace 34 was based solely on communication, and Mace 34′s awareness about Mace 33 was based on communication and limited visual observations. After Mace 34′s fuel state dictated terminating the tactical maneuvering, Mace 33 failed to recognize this as a trigger event and made a (poor) tactical decision to continue with the TTP execution. At that point, both implicit coordination and communication failed, and TSA was further degraded by the Mace 33′s failure to communicate his tactical maneuver. Soon after the transactive memory system also became unrepresentative of the situation, as Mace 33 assumed Mace 34 knew both aircraft's locations. The correct representation was never reestablished before the collision. No attempts were made to regain sufficient TSA with communication. Mace 33 and 34 both reestablished their individual situation awareness, but that occurred too late for them to build and reestablish the required TSA and to avoid collision. Before the accident Mace 33 was still engaged in tactical taskwork. However, as indicated by the use of the boresight FCR mode, Mace 34 was not: Mace 34 was solely concerned with deconfliction. At that point, it was questionable if Mace 33 and Mace 34 were working interdependently and adaptively toward a common goal, i.e., if they formed a team (Salas et al., 1992).

To conclude, the root cause of the mishap was a failure in the coordinate competency, which resulted in a poor TSA, an inability to regain TSA using explicit coordination and breakdown of the transactive memory system. Once the pilots were in a position to regain TSA and transactive memory, it was too late for them to avoid the collision. In comparison, besides communication, none of the human performance factors identified by the AIB considered Mace 33 and Mace 34 as a team. In fact, terms 'team' or 'teamwork' were not even mentioned in the accident report.

In air combat, teams exist to do things. As this case study demonstrated, the performance model illustrated in Figure 1 can help in explaining the interaction between the task- and teamwork, and how these contribute to team performance in air combat and in air combat training. The purpose of the model is not to shift the fighter pilots' focus from taskwork to teamwork. Rather, it attempts to find a balance between the two. Without such balance, it can be difficult to gain a holistic understanding about the rationale behind the successes and failures of air combat teams.

Discussion

Team performance in air combat has been extensively studied from the taskwork perspective. Research has successfully described the competencies flights use to execute their taskwork (Alliger et al., 2012; Alliger et al., 2013; C. M. Colegrove & Alliger, 2002), and how the performance of those teams can be measured (Mansikka et al., 2020). There have been some attempts to describe the teamwork of flights as well, but those studies have mainly adopted existing models of teamwork to the air combat context (Karp et al., 1999; Ohlander et al., 2019; Tsifetakis & Kontogiannis, 2019). Until now, unclassified research has not sufficiently explained how teamwork and taskwork interact and how they contribute to team performance in air combat. The performance model introduced in this paper fills this knowledge gap and clearly illustrates how teamwork and cognitive emergent states contribute to the flight's taskwork and combat effectiveness.

The proposed model respects the unique nature of single-seat fighter aircraft operations and appreciates the boundaries of teamwork and taskwork. The model is useful in several ways. The model can help in identifying the connection between the flight's performance output, taskwork and teamwork – even when the linkage is not apparent. Second, attempts to train teamwork to single-seat fighter pilots have not been highly successful. This is because any teamwork training which overlooks the unique nature of fighter operations and the task-oriented stance of the fighter pilots is unlikely to gain pilots' acceptance (see, e.g., O'Connor et al., 2012). Moreover, the model, while having a solid theoretical foundation, also speaks the language of fighter pilots and thus makes it easy for them to relate to it. Unlike many existing models of teamwork, the one proposed in this paper is specifically tailored for air combat and is equally suitable for the investigation of both failures and successes of team performance – whether the focus is on teamwork, taskwork or both.

The performance model presented builds on the known team- and taskwork constructs and mechanisms. However, instead of just repeating them, the model draws logical linkages between different competencies and emergent states thereby highlighting their interaction. In addition, unlike many previous models of teamwork, this paper shows how communication is best understood as a form of coordination rather than a separate competency. As such, communication should not be seen just as the verbal information exchange between pilots, but also as the interaction between the pilots and the system artifacts, and increasingly as the interaction between systems. Communication, while being a critical mechanism for air combat performance, is secondary to TSA and transactive memory when it comes to speed and accuracy of coordination. The role of communication, especially the communication between pilots, is essentially a tool for situation assessment and a fall-back coordination mechanism should TSA and transactive memory fail.

Although the performance model described is purely theoretical, the case study presented in the paper clearly demonstrates the potential of the model when the objective is to analyze team performance in air combat. While the case study dealt with an air combat training mission, the model itself is in no way limited to training scenarios. Realistic air combat training missions have the same team performance features as the real ones. As discussed in the paper, the model captures these features. Acknowledging the qualitative nature of the case study, the logical next steps toward a wide scale utilization of the model is to validate it using quantitative data extracted from real or simulated air combat missions. The first step has already been taken as the model has been utilized in simulated air combat missions where coordination was analyzed quantitatively (Mansikka et al., 2023). Future studies should strive to expand our understanding of team performance in air combat by exploring other aspects of team performance. The performance model introduced in this paper provides a sturdy handrail for such endeavors.

Disclosure Statement

No potential conflict of interest was reported by the author(s).

ORCID

Heikki Mansikka http://orcid.org/0000-0002-7261-6408
Don Harris http://orcid.org/0000-0002-2113-8848

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