A Bridge Between Cockpit/Crew Resource Management And Distributed Mission Training for Fighter Pilots

Robert T. Nullmeyer, Peter Crane, and **Glenn D. Cicero**
Warfighter Training Research Division
Air Force Research Laboratory
Mesa, Arizona

V. Alan Spiker
Anacapa Sciences, Inc.
Santa Barbara, California

Well-coordinated tactical teams are essential for mission success. Distributed mission training (DMT) has significant potential for improving this coordination. A parallel team training approach, cockpit resource management (CRM) training can provide valuable lessons learned regarding interactive crew processes that promote this coordination. Although, by definition, single-seat fighters do not have crews, pilots in a four-ship of F-16s, together with their weapons director, do form a tactical team, making CRM processes relevant to mission effectiveness. DMT provides scenario control that is not available in aircraft training. This control provides the capability to identify key behaviors exhibited by the most (and least) effective tactical teams. These behaviors can be translated into well-defined training objectives and associated measures of training effectiveness, which in turn will enable comparisons among alternative DMT training practices. Characteristics of effective CRM training across the services are summarized, including the need for concrete training objectives, a high degree of operational relevance, and instruction that is tailored to the needs of the participants. The key behaviors that are most consistently linked with effective crews in CRM research are compared and contrasted with behaviors that appear to affect mission effectiveness in DMT air-to-air, 4 v X scenarios. The latter behaviors were derived from observations made over the past 18 months as F-16 pilots received flight leader upgrade training at our Mesa Arizona DMT facility. Electronic Combat (EC) training was found to be a particularly fertile domain in earlier CRM research. The same holds true for DMT. Tactical behaviors for EC are also identified. Military researchers have made substantial progress over the past few years toward developing reliable measures of CRM. We conclude with a research plan to systematically capture more detailed quantitative and qualitative CRM data from DMT scenarios. The initial goal is to identify the CRM behaviors exhibited by the most (and least) effective fighter teams. Ultimately, these behaviors will be translated into well-defined training objectives from which process and outcome measures can be developed to enable comparisons among alternative DMT training practices.

ABOUT THE AUTHORS

Robert Nullmeyer is a research psychologist with the Air Force Research Laboratory, Warfighter Training Research Division (AFRL/HEA). Research interests involve cockpit/crew resource management training and measurement. He earned a Ph.D. in Experimental Psychology from the University of New Mexico.

Peter Crane is a Research Psychologist at AFRL/HEA. His major research interest is enhancing the effectiveness of Distributed Mission Training Systems. Dr Crane earned a PhD in Experimental Psychology from Miami University in Ohio.

Glenn D. Cicero is an engineer with AFRL/HEA. He has conducted investigations on the electronic warfare (EW) portion of training system designs, covering basic procedures training up to tactical mission training. He earned a B.S. Electrical Engineering Degree from the University of Colorado and has accumulated over 1000 flying hours in various aircraft to become familiar with the EW systems installed.

V. Alan Spiker is a principal scientist at Anacapa Sciences, Inc., Santa Barbara, CA. He is responsible for human factors research associated with advanced technology and has conducted field studies on mission planning and command and control systems for all branches of service. He has a Ph.D. in Experimental Psychology from the University of New Mexico and has been with Anacapa Sciences since 1982.

A Bridge Between Cockpit/Crew Resource Management And Distributed Mission Training for Fighter Pilots

Robert Nullmeyer, Peter Crane, and Glenn Cicero
Warfighter Training Research Division, Air Force Research Laboratory
Mesa AZ

Alan Spiker
Anacapa Sciences
Santa Barbara CA

INTRODUCTION

All the Services and many joint organizations are acquiring distributed-simulation capabilities to support collective training. The Warfighter Training Research Division of the Air Force Research Laboratory (AFRL/HEA) developed a comprehensive approach called distributed mission training (DMT) for applying this technology to mission planning, rehearsal, and training. In the Air Combat Command, DMT will replace many current simulation systems with interlinked mission training centers (MTCs) around the world. The resulting network of linked, high fidelity simulators will allow combat teams to train for the increasingly complex combat environments to which they are being committed.

As DMT technology matures, attention is now shifting toward developing effective instructional strategies and documenting value received from interactive, geographically dispersed simulation. Goals and expectations for distributed, simulation-based technology generally fall into two categories. One is to maintain or raise unit performance by acquiring comparatively less expensive distributed-simulation training systems to lessen the need for more expensive field training. The second is to provide team training experiences that go beyond the capabilities of live training ranges, including sophisticated data capturing and playback capabilities (Proctor & Lipinski, 1999).

Historically, measuring team performance has been a challenging task. The resulting lack of hard data continues to pose problems for cockpit/crew resource management (CRM) training. In its short history, CRM has undergone five distinct generations in definition and domain (Helmreich, Merritt, & Wilhelm, 1999), and multiple views still flourish concerning what it really is and how it is best trained. A lack of clearly defined training objectives in terms of student knowledge and skills hampered CRM training effectiveness evaluation until very recently, allowing both strong and weak programs to exist with little data to differentiate them. Research in all three services is painting a consistent picture: skills and behaviors, rather than recalling lists or defining terms, differentiate the most effective crews from the others. Some team skills appear to be fairly general, but many appear to be specific to platform, and even mission phase (Bergondy, Fowlkes, Gualtieri, & Salas, 1998; Proctor & Lipinski (1999); Thompson, Tourville, Spiker, & Nullmeyer, 1999). These results emphasize the need for hands-on CRM training that is tailored to the needs of the population being trained, yet such programs are the exception rather than the rule.

In the Air Force, CRM training guidance is given in Air Force Instruction 11-290, *Cockpit/Crew Resource Management Training Program.* CRM program goals are to maximize operational effectiveness and combat capability while preserving Air Force personnel and equipment. CRM training content is organized into six core areas: situational awareness, crew coordination/flight integrity (includes leadership and assertiveness), communication, risk management/decision making, task management (includes adaptability and flexibility), and mission planning/debrief (includes mission analysis).

To accurately define CRM training requirements and assess CRM training effectiveness, visibility into crew processes and their links to mission outcome is essential. The Naval Air Warfare Center Training System Division has made substantial progress in this area with the development of an instructional approach known as event-based training. (Fowlkes, Dwyer, Oser, and Salas (1998). In this approach, explicit linkages are created among learning objectives, exercise events, performance measures, and after-action feedback.

Proctor & Lipinski (1999) describe an application of event-based training in the Army's Close Combat Tactical Trainer (CCTT). The CCTT is a distributed-simulation system for Cavalry and Mechanized Infantry, Platoon through Battalion/ Task Force training. It consists of networked vehicle simulators with semi-automated forces, combat support workstations, computer networks and protocols, and after-action review systems. At the aggregate level across all subtasks, a CCTT-trained unit performed significantly better than three baseline units during a follow-on exercise at the National Training Center. Proctor & Lipinski suggested that this superior follow-on performance might reflect improving teamwork, command/control/ communication, and unit processes during training in the CCTT. However, crew performance data in early CCTT testing was focused on outcome measures such as loss exchange ratio, and showed little change during training. Evaluators noted a lack of clear training objectives during early testing, and that training exercises were commonly conducted without prior planning or briefings.

To increase visibility into team process improvement, Proctor & Lipinski applied the Navy's event-based training approach. Teamwork quality ratings showed statistically significant improvement from the first to the second CCTT session in all four categories measured (communications, information exchange, team leadership, and supporting behavior) and in 13 of 15 behaviors within these categories. Loss effectiveness ratios actually dropped (but not significantly), as opposing force capabilities increased. Conclusions were: (1) distributed simulation satisfies at least two training needs – teamwork and Command, control, and communication (C^3), (2) traditional outcome measures such as loss exchange ratios are not adequate as stand alone measures to track the impacts of CCTT in a training context, and (3) teamwork and task performance measures are viable and necessary to provide a more complete assessment of performance in distributed simulation systems.

Bergondy, Fowlkes, Gualtieri, & Salas (1998) described an insightful analysis of debrief comments by instructors during Wing-level predeployment training at the Naval Strike and Air Warfare Center. Three training phases are conducted routinely. The first addresses planning and execution of specific missions such as suppression of enemy air defenses combining and utilizing different tactical aircraft. The second integrates all wing elements with battle group assets to conduct tactically sound power projection missions. In the final phase, air wings respond to an evolving, four-day scenario. Bergondy, et al. reported instructor debrief comments pertaining to planning, briefing, and execution separately and concluded that the competencies most frequently addressed by instructors in debriefing varied across these phases. Leadership was a particularly important competency during planning to prioritize planning tasks and integrate inputs. Interpersonal skills such as assertiveness were also valuable during planning. The latter, however, became less important, and even inappropriate, during mission execution. During briefing, a key team competency was building a common understanding of the mission. Organization and content of the mass brief were found to be critical. Precise, unambiguous communication and the ability to accurately recognize and react to environmental cue patterns were important competencies in mission execution. Throughout training, instructor feedback was predominantly negative, suggesting additional room for improvement. Bergondy, et al. specified training interventions to help develop these varied competencies.

AFRL/HEA recently sponsored a series of studies that addressed the CRM behaviors exhibited by mission ready Air Force aviators. Silverman, Spiker, Tourville, and Nullmeyer (1997) demonstrated an empirical link between CRM and mission performance for MC-130P crews as they planned and executed a simulator mission representing a tactical environment. Time management, allocation of functions across crewmembers, tactics employment, situational awareness (SA), and command-control-communication (C^3) were observed and rated during mission preparation and four mission execution phases. Overall crew coordination ratings were highly correlated with total mission performance ratings, accounting for 75% of observed variability. The importance of individual crew coordination elements and performance varied across mission phases. SA and time management were strong predictors of mission planning ratings. Allocation of functions among crewmembers was the strongest predictor of mission performance during the low-level phase. Time management was a particularly important element for air drop, tactics employment was an unusually strong predictor of air refueling performance, and all elements except C^3 appeared to be related to landing in a potentially hostile environment. Surprisingly, C^3 did not appear to be major discriminator of performance in any of the mission elements. Leadership, on the other hand, emerged as a major factor in mission performance even though it was not part of the initial study design.

In a follow-on study, CRM and mission performance data were collected from 16 C-5B crews during a challenging simulated nighttime airlift mission complicated by poor weather, post-takeoff landing gear malfunctions and eventual engine failure (Spiker, Tourville, Bragger, Dowdy, & Nullmeyer, 1999). A significant correlation was found between CRM and mission performance ratings. Some definite, concrete behaviors characterized the most effective crews. In planning, effective crews challenged assumptions in their mission tasking, actively engaged in map study, applied their own experiences, and ensured direct information flow between pilots and flight engineers. During mission execution, the successful crews sequenced events so that trouble shooting was completed before the aircraft descended below 10,000 ft., had a strong functional leader who was adept at delegating specific duties (assigning troubleshooting to the senior flight engineer), and, and directly exchanged information between one of the pilots and one of the flight engineers.

A third study addressed CRM behaviors and mission performance of MH-53J crews during preparation for, and execution of a complex combat scenario using networked simulator training (Thompson et al. 1999). Again, CRM ratings accounted for a large percent of mission performance (70%). As had been observed in other studies, CRM-performance correlations varied across specific mission phases. Correlations between mission planning performance and six of seven CRM categories were statistically reliable (mission evaluation, SA, crew coordination, communication, risk management, and tactics employment). The last CRM category, time management, was positively correlated ($r=.61$), but failed to reach the criterion for statistical significance. Time management and tactics employment were statistically reliable predictors of low level performance. Mission evaluation, SA, and risk management were statistically reliable predictors of the final phase of the scenario, in which crews needed to recognize the need to abandon their damaged helicopter.

Lessons Learned from CRM Studies

Several themes emerge across these studies. Three in particular—the importance of understanding the team processes that lead to mission performance, the role of leadership in tactical team performance, and the impact of planning on subsequent mission performance—will be explored.

Importantly, the researchers cited above all emphasized crew or **team processes**, usually in conjunction with outcome measures such as miss distance scores or loss exchange ratios. With this approach, the importance of good teamwork for effective crew or team performance has been repeatedly demonstrated. Team competencies for large tactical operations were reported by Bergondy, et al., 1998. Silverman et al., 1997; Spiker et al., 1999; and Thompson et al., 1999 reported statistically significant correlations between CRM and mission performance for MC-130P, C-5, and MH-53J crews, respectively. Proctor & Lipinski reported improved CRM and improved mission performance. Huddlestone et al., 1999 showed positive transfer of team skills training to the aircraft.

Process/performance relationships are allowing training to be better matched with actual needs of the target population. Interestingly, some CRM elements appear to have limited utility in certain settings. Bergondy, et al. found that adaptability, which was often a major factor in CRM research and training, is viewed negatively in large tactical teams during mission execution unless covered by explicit contingency planning previously. Silverman et al. reported that C^3 was not related to mission outcome for MC-130P crews. In retrospect, this community has likely evolved toward minimizing verbal communication due to the nature of their missions and they, in fact, refer to themselves as "the quiet professionals."

Electronic combat (EC) is a particularly interesting task from the perspectives of team competencies and DMT training effectiveness.

Bergondy et al. reported that threat awareness was a frequent debriefing item. Huddelstone et al. reported 14% and 13% failure rates for defensive considerations and radar honing and warning receiver awareness respectively without simulator training, which reduced to 4% and 2% failure rates with simulator training.

Second, **leadership** frequently emerges in CRM research as an important characteristic of effective tactical teams. Though early instruments were not explicitly designed to capture the role of leadership, recent AFRL CRM studies have shown that successful crews are more likely to have a strong leader starting in mission planning. Among MC-130P crews, this leader formed the core of an effective "hub-and-spoke" communication structure (Nullmeyer & Spiker, in press). For MH-53J crews, a five-point leadership index was assigned to each crew (1=no leader present; 5=leader present throughout all phases), and it significantly predicted (r=.71) mission performance (Thompson et al.). The Navy showed that team leadership is particularly important during planning, as strong leaders will prioritize planning tasks and integrate inputs so that an efficient plan can be developed within a constrained time frame (Bergondy et al.). Good leaders also use personnel effectively and "keep everyone on the same page" (Spiker et al., 1997). While the leader is typically the aircraft commander, we have observed instances where successful crews had a non-pilot in charge, such as a senior flight engineer or navigator.

Third, the importance of **mission planning** has been repeatedly documented (Bergondy et al.; Silverman et al.; Spiker et al.; and Thompson et al.). Bergondy et al. reported that well over half the debriefing topics in Navy Air Wing Integration Training involved mission planning or briefing behaviors. Despite the demonstrated importance of good mission planning, it is often overlooked. Dwyer et al. reported that planning was not rated by any of the aviator observers in either of their DMT case studies. Proctor & Lipinski reported that early exercises using the CCTT frequently omitted planning and briefing.

APPLYING CRM LESSONS LEARNED TO F-16 FOUR SHIP DMT

Training for single-seat fighter pilots has traditionally focused either on systems operation or on mission performance in large-force exercises such as Red Flag. Hawley (1997) referred to these emphases as "blocking and tackling" and "scrimmage" respectively. One of the goals of DMT is to expand the range of capabilities to train teamwork skills within a group of fighters, and between fighters and supporting elements such as AWACS weapons controllers. Research on training effective warfighter team performance is being conducted at AFRL/HEA using a testbed DMT system consisting of four F-16 simulators, control and observation systems, computer generated forces, and replay/debrief systems located in Mesa, Arizona, connected to an AWACS simulation facility at Brooks AFB, Texas and a constructive air defense system located at the Air Force Information Warfare Center, Kelly AFB, Texas. Using this testbed system, teams of F-16 pilots and AWACS weapons controllers have participated in several DMT exercises that have focused on composite force missions, four-ship air-to-air combat, and flight lead upgrade training (Crane, 1999b; Crane, Bennett, and Robbins, 2000). Initial studies focused on assessing improvements in mission performance over several days of training.

In the RoadRunner 98 composite-force exercise (Crane 1999b), indicators of mission success such as bomb miss distance and number of aircraft lost to surface and airborne threats showed that experience using DMT systems enhanced team performance. Feedback from RoadRunner 98 participants indicated that performance enhancements primarily resulted from increased skills on tasks that are not frequently practiced in the aircraft such as using air-to-air radar to sort and target multiple aircraft, and improved coordination between warfighter teams such as F-16 pilots and a forward air controller or pilots and AWACS air weapons controllers. Pilots and controllers in the RoadRunner 98 exercise rated DMT as most effective for training multi-ship, beyond-visual-range air combat against multiple, maneuvering targets. Based on this finding, research was conducted on the training potential for DMT focused on this mission (Crane, 1999a).

Prior to conducting DMT air-to-air training research, instructor pilots, flight commanders, and RoadRunner 98 participants were interviewed to identify the mission skills that were well suited for DMT. Skills for wingmen, 2-ship flight leads, 4-ship leads, and instructors are shown in Table 1 with classic CRM skills in bold print. Based on this information, a five-day training protocol was developed incorporating two training periods per day with increasing mission complexity over the week. Early in the week, training sessions consisted of multiple setups with four F-16s supported by AWACS controllers performing a fighter sweep against four MiG-29s or Su-27s. These engagements were flown with fuel frozen and the F-16s invulnerable to enemy weapons (i.e., shields-up). Later in the week, teams flew defensive counter-air missions opposed by multiple waves of four or more enemy fighters including strike aircraft and high-fast flyers (over 500 knots airspeed and 35,000 feet altitude). During these engagements fuel was flowing, enemy airspace was defended by surface to air missiles, and F-16s that were hit by enemy weapons were removed from the fight (shields-down). The changes in skill levels were best summarized by a wing training officer who participated on one of the teams as, "Overcome simisms first, initial proficiency second, and exponential improvement after that."

Team Processes

Classic CRM behaviors are important in DMT. CRM researchers in all three services have focused their efforts on discovering the processes that lead to effective performance. In this vein, Dwyer, Oser, Salas, and Fowlkes (1999) measured learning in two case studies where DMT was used to support Close Air Support training. Performance ratings for four dimensions of teamwork during planning--coordination, communication, SA, and adaptability--improved over training days. Three dimensions—coordination, communication, and SA-- were rated for the contact point and attack phase of mission execution. Improvements over training days were greatly attenuated relative to the changes reported for planning. The authors concluded that event-based training provided a useful framework in which to measure team performance in a distributed training environment. They also reported that clustering performance data by mission phase provided a strong diagnostic capability for guiding and organizing after action review sessions.

Huddlestone, Harris, and Tinworth (1999) reported transfer of training from multi-player simulation to the aircraft. These researchers assessed the impact of training in a low-cost, multi-player, networked desktop simulation system (named JOUST) on subsequent RAF Toronado crew performance of two-ship tactics inflight. Student performance was documented during the Radar to Visual Pairs phase of Operational Conversion Unit training. Specific areas studied were communications, threat assessment, decision-making, and visual weapon employment. Performance of students who trained with JOUST was compared to performance of students who spent an equivalent amount of time training in a single crew trainer. The group receiving JOUST training showed a marked reduction in failure rates across the six inflight sorties, ranging from 0% to 10%, compared to 9% to 18% for the control group. Failure rates across all sorties fell in 8 of 9 categories for students who received JOUST training. Failure rates for visual *communication/ coordination* fell from 28% to 8%, weapons employment visual from 16% to 2%, chaff and flare employment 18% to 3%, tactical *leadership* from 18% to 6%, radar *awareness* from 13% to 2%, defensive considerations from 14% to 4%, and tactical *awareness*, from 9% to 3%. Of note is the improvement in both classic CRM and technical skill areas, with CRM categories italicized.

CRM and electronic combat. EC is proving to be a particularly interesting task from a team-process perspective because of the inherent inter-relationship among the six key Air Force CRM behaviors and EC principals. Of these six, SA, flight integrity, and communication appear to be most closely related to EC performance. Under the SA category, EC can be considered a function of sensor management which includes pilot awareness of radar indications, radar warning receiver (RWR) indications, other sensors (receivers on jammers, infrared sensors, etc.), and any correlation that may exist between these systems in addition to threat awareness and knowledge. Flight integrity behaviors related to EC were threat calls to and from other elements in the formation and threat countermeasures, including maneuvers, chaff and jamming, and cooperative electronic support. Communication between AWACS and the four-ship, and communication between flight elements are both highly predictive of EC performance, with radio discipline being a key consideration.

In our experience with DMT, the quality of EC training is strongly influenced by the quality of CRM principles learned and practiced. Behaviors observed during EC training prove that crews operating under the core CRM practices exhibit

Table 1. Mission skills rated by F-16 pilots as well supported by DMT

Wingman, fundamentals	- Radio **communication** in accordance with standards - Radar mechanization - Maintain **mutual support** - Stick with the plan - Build **situation awareness**
2-ship flight lead	**- Keep track of your wingman** **- Use the wingman's radar** **- Be directive** **- Be alert for changing priorities**
4-ship flight lead	- **Keep track of 2nd element and the enemy** - Create, brief, and execute "what-if" plans - **Specify lessons learned for all**
Instructors	- Identify problem areas - **Communicate** and remediate

better threat awareness and reaction (RWR awareness) and maintain flight discipline such that radio calls are not cluttered and flight formation is maintained to allow for cooperative support. Discussions in debrief support this conclusion. In a number of instances, causes leading to flight elements being engaged/ destroyed by threats were degraded SA, flight integrity and communications, especially threat calls. For missions where flight elements established and maintained proper SA, flight integrity and communications, there was a marked reduction in losses.

Leadership

DMT's value for leadership training. One unanticipated finding in RoadRunner 98 was that teams used the week of DMT to provide leadership experience for pilots who were participating in Flight Lead Upgrade (FLUG) training in their squadrons. During FLUG training, pilots learn the skills required to plan, brief, lead, and debrief combat missions. In DMT, upgrading pilots were given opportunities to brief and lead the four-ship flight and to serve as the leader of a two-ship element within the flight. Based on feedback from instructors participating in DMT, a program to utilize DMT to augment F-16 FLUG training was undertaken in early 1999 (Crane et al., 2000).

Flight lead upgrade training. DMT—FLUG training consists of an eight-session protocol for teams of two upgrading pilots, two wingmen, and one instructor supported by air weapons controllers. Each upgrading pilot is given the opportunity to brief, lead, and debrief, four missions of increasing complexity (see Crane et al. 2000). Between June 1999 and February 2000, 12 upgrading pilots have participated in DMT research. Measures of mission success such as F-16 losses to enemy fighters and fratricides, number of enemy fighters killed, and percentage of valid missile shots demonstrate that teams increase their proficiency over a week of training. Further, feedback from upgrading pilots and their instructors shows that participation in DMT—FLUG training enhances performance on subsequent training missions. Measures of mission performance, however, do not address the specific skills that are being affected by experience using DMT systems. Recently, DMT—FLUG missions have been observed using the Air Force's six core areas of CRM to identify the flight leader skills that are being enhanced by DMT. The goal of this effort is to develop instructional strategies for DMT that will focus future training events on the skills that will most improve mission effectiveness. Observations confirmed the F-16 instructor pilot's remark that pilots' must first develop basic proficiency but then improve their performance "exponentially." Figure 1 summarizes the skills that were observed.

Missions were conducted in three phases: brief, fly, and debrief while skills were characterized as individual, leadership, or team. During early DMT—FLUG training, changes in performance were focused on individual skills and basic leadership. All pilots worked to improve their radar mechanization skills (using the modes and capabilities of the air-to-air radar to detect, target, and sort multiple maneuvering aircraft), communication in accordance with Air Force

Training focus **early** in DMT—FLUG protocol		Mission Phase		
		Brief	Fly	Debrief
Skill Domain	Individual	• Understand game plan and options	• Radar mechanization • Correct communication	
	Leadership	• Present plan effectively • Flight lead as primary shooter	• Identify tactical situation • Execute game plan	• Reconstruct mission
	Team		• Maintain mutual support • Basic four-ship tactics	

Training focus **later** in DMT—FLUG protocol		Mission Phase		
		Brief	Fly	Debrief
Skill Domain	Individual		• Maintain SA during complex scenarios	
	Leadership	• Work with AWACS/GCI controllers • Flight lead as radar quarterback	• Identify contingencies and call audibles • Change comm priorities as scenario develops	• Identify lessons learned
	Team	• Rehearse radio calls	• Complex four-ship tactics	• SA building communication

Figure 1. Observed changes in training focus during DMT—FLUG exercise.

standards, executing game plans using basic tactics, and maintaining mutual support within the flight. Upgrading flight leaders focused on presenting their game plans clearly during the briefing, identifying the tactical situation and executing the briefed tactic, and reconstructing the mission during debrief. Two to four DMT missions were required to build satisfactory levels of proficiency in these skills. At this point, under the leadership of their instructor pilot, pilots began to focus on enhancing their teamwork skills. Upgrading flight leads worked more closely with the AWACS controllers during mission briefings. Upgrading pilots also changed their leadership strategy from being the primary shooter to being the "radar quarterback" with wingmen doing the shooting while the leader directed the fight. With increased confidence in their basic skills, teams incorporated more complex tactics into their game plans and were able to maintain SA during these engagements. One behavior that supported this capability was rehearsing radio calls during mission briefing. The flight lead would describe a situation using the whiteboard and say, "If this happens, then my call will be …and your reply will be… ." This behavior was reinforced during debrief when pilots and controllers reviewed their communication. Early in the week, teams focused on correct communication and avoiding radio clutter. Later in the week, teams focused on changing communications priorities as an engagement developed and using effective communication to build each others' SA.

During DMT—FLUG, scenarios were designed using a strategy called deliberate training (Crane 1999a and c). Similar to event-based training, deliberate training allows instructors to generate scenarios to enhance specific skills. By using methods developed to support CRM research, instructional designers for DMT will be able to focus deliberate training on specific skills and behaviors that enhance mission performance.

Mission Planning

As a cornerstone of military doctrine, the need for good mission planning enjoys unequivocal anecdotal support. A classic illustration is the Japanese failure at the Battle of Midway compared to their astounding success at Pearl Harbor. For the latter, "fliers were trained to memorize their attack targets, attack routes, and attack methods," whereas at Midway, air combat preparations were "limited," with no opportunity to rehearse "coordinated action between contact units, illumination units, and attack units" (Prange, 1982). Operationally, planning is considered to be a "preparation for specific actions generated ahead of time" (Taylor, 1993), a "substitute for experience" (Klein & Miller, 1993), or a method to provide "enhanced confidence of the men in themselves, their leaders, and their plan" (Wilmot, 1945).

While planning's importance for military success is unquestioned, its cognitive aspects (e.g., map study, what-iffing) create challenges for constructing reliable measures to support experimental studies of its component processes. To this end, the services have applied an array of methods to gauge the impact of planning quality on subsequent mission performance. These include post-exercise surveys; critical incident analyses, evaluation of intermediate products, retrospective interviews with planning experts, concurrent interviews with participants, concurrent ratings by independent observers, and structured checklists. Despite this diversity, a substantive knowledgebase has been amassed from which valuable lessons learned can be applied to the DMT-fighter environment.

Time spent planning is important. Though at odds with the constraints of a rapidly changing tactical environment, studies consistently show that crews who spend more time planning are more successful. In Thompson et al.'s (1999) MH-53J study, crews were permitted up to several hours to plan for their simulator mission. Time spent planning correlated significantly (r=.76) with subsequent mission performance. Ruscoe and Cary (1984) surveyed staff from six US armor battalions and found that battalions spending more time planning were independently scored as more effective. Of course, it is not simply the amount of time that drives improved performance, but what the crew does with that time. Observations of planning sessions show that effective crews use this time to acquire and understand information; perform a detailed review of threats, terrain, weather, and timing; check waypoints; revise the route plan; and customize their own map (Thompson et al., 1999).

High quality briefings and products are important aspects of good planning. Although planning is a cognitively intense activity, there are concrete, overt signs of good planning. Two of the most salient indicators of good planning are that crews give high quality briefings prior to the mission and generate high quality products during the planning session. In observing MC-130P crews, we found that ratings of products generated during planning (e.g., map annotations, threat laydowns, terminal area sketches) were significantly correlated (r=.60) with performance (Spiker et al., 1997). In a study of 16 C-5B crews undergoing continuation training, we found that quality of the mission briefing predicted performance (r=.43), where successful crews gave briefings that included all crewmembers, covered all critical aspects of the mission (ingress, egress, threat evasion, emergencies, etc.), and addressed each planning product in detail (Spiker et al, 1999).

Preparation of backup or contingency plans is essential. The fluid nature of the tactical environment frequently requires that crews change their original plan in response to unforeseen events (e.g., new threats, weather, equipment malfunction). Not surprisingly, we see that the more effective planning sessions are ones where contingency or backup plans have been developed. Indeed, the presence of a viable contingency plan is a frequent characteristic of good plans. Fallesen (1993) noted in his study of individual differences that the better planners were more likely to look for ways that their original plan could go wrong. In studying the behavior of student Army planners, Fallesen and Michel (1991) found that lack of contingency planning was characteristic of the poorest planners, and often resulted from the lack of certainty about enemy intentions. MacMillan, Entin, and Serfaty (1993) had three super-experts rate the performance of 26 military officers on tactical planning tasks. Experts planned contingency operations more thoroughly, identified more potential problems with the original plan, and were more likely to anticipate changes in the tactical situation. Thompson et al. (1999) found that better planning MH-53J crews performed extensive what-iffing, often chair-flying each step to identify problems and options, as well as create backup plans. In reviewing an extensive database of experienced instructor recollections, Bergondy et al. (1998) noted that contingency planning was one of the most prevalent team competency behaviors. Similarly, Dwyer et al, (1999) showed that contingency planning was reflective of a more general dimension of Team Adaptability, which was composed of back-up plans, smooth transitions to back-up plans, and quick adjustments to situational changes.

Confidence in the plan is important. In assessing the operational effectiveness of an advanced weapon systems trainer, Nullmeyer, Bruce, Conquest, & Reed (1993) queried Air Force and Army personnel before, during, and after their use of a simulator in rehearsing for a joint training exercise. They found that rehearsal had perhaps its biggest impact in instilling confidence in the plan, as personnel who used the device had greater confidence that the plan would work and the mission would be successful. This confidence appears to be a more general feature of good planning, as effective crews have more confidence in their plan (Spiker & Nullmeyer, 1995). This stems from knowledge gained from thorough preparation given the time available to do so. Thus, the most confident crews are ones who aggressively challenged assumptions in their mission tasking, conscientiously engaged in map study, decomposed the mission in a logical (i.e., by time, events) fashion, applied their own real-world experiences, and ensured frequent and direct information exchange between the pilots and other crewmembers (Spiker et al., 1999).

Successful planning will promote shared understanding by all participants. Along with confidence, effective planning produces a shared understanding by mission participants of the essential mission elements. Indirect evidence for the importance of this understanding comes from Fallesen, Carter, Perkins, Michel, Flanagan, & McKeown's (1992) finding of significant correlations between route planning and situation awareness. Similarly, both Spiker et al. (1997) and Spiker et al. (1999) observed significant correlations between planning quality and SA in their studies of Air Force crews. Recently, Stout, Cannon-Bowers, Salas, and Milanovich (1999) have established a direct link between planning quality and shared awareness, postulating that a by-product of good planning is that participants develop a shared "mental model" which lets them utilize efficient communication strategies during high workload periods. This was tested with 40 two-person student crews flying a low-fidelity helicopter simulator. During planning, a cognitive probe test was administered to determine each crew's cognitive model of the mission. As predicted, crews who planned better had better scores on the shared mental model test, and they were in fact able to perform better during high workload (performing navigation and defense tasks simultaneously) periods. Bergondy et al. (1998) also found that a key team competency is to build a common understanding of the mission, with this shared understanding being most effectively created during the mission briefing.

FUTURE RESEARCH

While research addressing team processes in DMT is clearly in its infancy, these early studies suggest that team processes are important contributors to mission performance in the DMT environment. Small sample sizes to date have precluded practical analyses of statistical significance, but findings parallel those reported in more robust CRM studies. Karp, Condit, and Nullmeyer (1999) conducted extensive interviews with F-16 squadron or wing leaders, instructors, and students. Two thirds of the respondents indicated a preference for "hands-on"learning, suggesting that effective CRM instruction needs to include the opportunity to practice CRM behaviors. Recommendations for improving CRM training were also solicited. The highest frequency responses were (1) assure that the concept of training enhances the learning process, (2) assure course delivery is applicable to the audience, (3) consider a term other than "CRM" for single-seat fighters, (4) make CRM tactically relevant and applicable to single-seat fighters, and (5) use simulators to reinforce CRM training. Clearly, DMT has the potential to address each of these recommendations, including the ability to practice sound CRM behaviors in a relevant, hands-on environment. However, a better understanding of team processes in F-16 four-ship operations and their relationships with mission performance is needed to identify the most critical training needs. We anticipate three research thrusts.

Specify and collect team process and mission performance data from F-16 pilots and the weapons director. Much of our information to date concerning team dynamics in DMT is anecdotal, with earlier DMT research often being focused on performance during mission execution. The aperture needs to be widened in two dimensions. First, mission performance data need to be augmented by systematic process data based on observable behaviors to document the key processes leading to mission success or failure. Second, the domain needs to span all activities from mission tasking through debrief. One impact of this is ensuring that mission planning is included in the training schedule.

Identify key team processes that are highly correlated with mission performance. As has been done in earlier CRM research, team process and mission performance data can be correlated to identify probable high-payoff areas for DMT training. Correlations identify those areas where there is (1) substantial variability across pilots or crews and (2) a demonstrated link between team dynamics and performance. Previous analyses revealed substantial differences between the CRM behaviors that are most closely linked to mission outcome and the generic, one-size-fits-all content of traditional CRM instruction. In particular, the behaviors exhibited by the most effective crews were not part of existing training programs. Although we focused on leadership and planning here, other CRM elements will undoubtedly come into play. In addition, interactions among CRM elements are commonplace and need to be identified.

Provide content for well-defined training objectives. Prioritized content based on the behaviors exhibited by representatives of the target training populations has proven to be a powerful foundation upon which to build relevant CRM courses. The same is likely to be true of DMT. Clearly, research findings need to be augmented with subject mater expert inputs and other data such as after-action reports, accident/incident reports, and content analyses of existing training records. The result will be DMT training objectives that focus on the greatest need and the areas of highest potential payoff. The parallels between the emerging capabilities of DMT and the recommendations of F-16 pilot concerning CRM training lead us to believe that DMT is an essential medium for achieving the kind of team training program envisioned by the members of this community.

REFERENCES

Bergondy, M., Fowlkes, J., Gualtieri, J. & Salas, E. (1998). Key team competencies for Navy air wings: A case study. Proceedings of the 19th Interservice/ Industry Training Systems and Education Conference. Orlando, FL.

Crane, P. (1999a). Designing training scenarios for distributed mission training. Presented at: 10th International Symposium on Aviation Psychology, Columbus, OH.

Crane, P. (1999b). Implementing Distributed Mission Training. Communications of the ACM, *42* (*9*), 91-94.

Crane, P., Robbins, R., & Bennett, W. (2000). Using Distributed Mission Training To Augment Flight Lead Upgrade Training. In, Proceedings of 20th Industry/Interservice Training Systems and Education Conference, Orlando, FL.

Crane, P., Schiflett, S. G., & Oser, R. L. (2000). *RoadRunner 98:* Training Effectiveness in a Distributed Mission Training Exercise (AFRL-HE-AZ-TR-2000-0026). Mesa, AZ: Air Force Research Laboratory, Warfighter Training Research Division.

Dwyer, D., Oser, R.L., Salas, E., & Fowlkes, J.E. (1999). Performance measurement in distributed environments: Initial results and implications for training. Military Psychology, 11(2), 189-215.

Fallesen, J.J. (1993, September). Overview of Army tactical planning performance research (ARI Technical Report 984). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

Fallesen, J.J., Carter, Jr. C.F., Perkins, M.S., Michel, R.R., Flanagan, J.P., & McKeown, P.E. (1992). The effects of procedural structure and computer support upon selecting a tactical course of action (ARI Technical Report 960). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

Fallesen, J.J. & Michel, R.R. (1991). Observation on command and staff performance during CGSC Warrior '91 (ARI Working Paper LVN-91-04). Fort Leavenworth, KS: U.S. Army Research Institute for the Behavioral and Social Sciences.

Fowlkes, J., Dwyer, D.J., Oser, R.L., & Salas, E. (1998). Event-based approach to training (EBAT). International Journal of Aviation Psychology, 8(3), 209-221.

Helmreich, R.L., Merritt, A.C.. and Wilhelm, J.A. (1999). The evolution of crew resource management training in commercial aviation. International Journal of Aviation Psychology, 9(1), 19-32.

Huddlestone, J., Harris, D., & Tinworth, M. (1999). Air combat training – the effectiveness of multi-player simulation. Proceedings of the 20th Interservice/Industry Training Systems and Education Conference. Orlando, FL.

Karp, M.R., Condit, D., & Nullmeyer, R.T. (1999). Cockpit/crew resource management for single-seat fighter pilots. Proceedings of the 20th Interservice/Industry Training Systems and Education Conference. Orlando, FL.

Klein, G., & Miller, T.E. (1999). Distributed planning teams. International Journal of Cognitive Ergonomics, 3(3), 203-222.

MacMillan, J., Entin, E.B., & Serfaty, D. (1993). Defining and assessing expertise in a complex domain—measures based on theory. Paper presented at the 37th Annual Meeting of the Human Factors and Ergonomics Society, Seattle, WA.

Nullmeyer, R.T., Bruce, P.D., Conquest, M., & Reed, E.T., & Spiker, V.A. (1992). Using the MH-53J weapon system trainer/mission rehearsal system: Initial assessments and lessons learned. Proceedings of the 14th Interservice/Industry Training Systems and Education Conference. Orlando, FL.

Nullmeyer, R.T. and Spiker, V.A. (In press). The Importance of Crew Coordination in MC-130P Mission Performance: Implications for Training Effectiveness Evaluation. Military Psychology.

Prange, G.W. (1982). Miracle at Midway. New York: Penguin Books.

Proctor, M.D. & Lipinski M.J. (1999). Measuring the contribution of distributed simulation to unit training. Proceedings of the 20th Interservice/ Industry Training Systems and Education Conference. Orlando, FL.

Ruscoe, G.C., & Cary, J.S. (1984). Comprehensive technical report of the inquiry into the application of living systems theory to 41 U.S. Army battalions: Executive Summary (ARI Research Note 84-132). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences. (AD A148 156).

Silverman, D.R., Spiker, V.A., Tourville, S.J., & Nullmeyer, R.T. (1997). Team coordination and performance during combat mission training. Proceedings of the 19th Interservice/Industry Training Systems and Education Conference. Orlando, FL.

Spiker, V.A. & Nullmeyer, R.T. (1995, September). Measuring the effectiveness of mission preparation in the special operations forces. (AL/HR-TR-1995-007). Mesa, AZ: Aircrew Training Research Division, Armstrong Laboratory.

Spiker, V.A., Nullmeyer, R.T., Tourville, S.J., & Silverman, D.R. (1997, September). Effects of mission preparation on crew combat mission training performance. Paper presented at the 41st Annual Meeting of the Human Factors and Ergonomics Society, Albuquerque, NM.

Spiker, V.A., Tourville, S.J., Bragger, J., Dowdy, D. & Nullmeyer, R.T. (1999). Measuring C-5 crew coordination proficiency in an operational wing. Proceedings of the 20th Interservice/Industry Training Systems and Education Conference. Orlando, FL.

Stout, R.J., Cannon-Bowers, J.A., Salas, E., & Milanovich, D.M. (1999). Planning, shared mental models, and coordinated performance: An empirical link is established. Human Factors, 41(1), 61-71.

Taylor, R.M. (1993, October). Human factors of mission planning systems: Theory and concepts. 2-1 through 2-8. Presented at AGARD Lecture Series on 'New Advances in Mission Planning and Rehearsal Systems.'

Thompson, J.S., Tourville, S.J., Spiker, V.A., & Nullmeyer, R.T. (1999, December). Crew resource management and mission performance during MH-53J combat mission training. Proceedings of the 20th Interservice/Industry Training Systems and Education Conference. Orlando, FL.