HUMAN-CENTERED DEVELOPMENT FOR DISTRIBUTED MISSION TRAINING SYSTEMS

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ABSTRACT

In a recent book, Donald Norman describes how products developed from lists of user demands often fail when they are integrated into work environments. According to Norman, failures occur because actual customers for a product and their needs are often different from the focus groups that were interviewed during product development. Further, Norman states that the design process is often a linear sequence of operations that inhibits interactions among members of the team. He recommends that designs should emerge from a process of observing customers at work together with frequent prototype evaluations by users and the design team including managers, engineers, software specialists, technical writers, and behavioral scientists.

The Air Force Research Laboratory, Warfighter Training Research Division, has applied this human-centered development process to create a four-ship, F-16 simulation testbed. The testbed has been used in a series of Distributed Mission Training (DMT) exercises with pilots and air weapons controllers. The goal of these exercises has been to identify and document how DMT systems can be designed and used most effectively to enhance mission skills. The lab's design team has used these exercises to observe warfighters at work and identify significant training needs. During and after each training exercise, feedback is used to determine how to refine the scenarios, procedures, and testbed systems to support a training environment that complements current flying training requirements. Exercises have included RoadRunner 98 (a composite force exercise), an air-to-air training evaluation study, and flight lead upgrade training. Collected data are being used to determine DMT strengths and weaknesses and to identify the best training uses of DMT. These data are also providing a basis for a performance measurement system to assess the effectiveness of training in DMT.

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INTRODUCTION

Distributed Mission Training (DMT) as envisioned by U.S. Air Force's Air Combat Command will replace many current simulation systems with interlinked Mission Training Centers (MTCs) located at Air Force bases around the world. The MTCs will create a network to support complex team and inter-team training. Engineers and researchers at the Air Force Research Laboratory, Warfighter Training Research Division (AFRL/HEA) in Mesa, Arizona, have been working for a number of years to support the realization of this DMT vision.

When the MTC concept is described to pilots, many of them suggest that DMT systems should be configured to recreate in simulation the capabilities of the best available live training ranges including real-time shot assessment and video debrief. The DMT environment, however, is not constrained by the limitations of training ranges. DMT can support training scenarios that are rarely conducted on ranges due to resource constraints and can provide information to participants for run-time observation and debrief that is unavailable on training ranges. AFRL/HEA has created human-centered development teams including engineers, subject matter experts, behavioral scientists and operational warfighters to investigate how to best design and use DMT systems to increase training effectiveness. These teams are the key in the continuing effort to determine the best applications of DMT. They will also focus research and development efforts on how to structure DMT training events that enhance training effectiveness and complement flying training.

This team approach has been used at the lab to build several generations of low-cost simulation devices that meet user needs (Boyle & Edwards, 1992; Platt & Crane, 1993). AFRL/HEA has recently developed a DMT testbed that includes four F-16 simulators with high-resolution 360° visual display systems (Best, Wight, & Peppler,1999), an A-10 simulator, computer-generated forces, data logger, control console, plus observation and replay systems (Crane 1999a). The effectiveness and usability of the systems in this testbed have been evaluated in a series of MTC exercises including a composite force exercise in mid-1998 (RoadRunner '98), air-to-air training evaluation studies in early 1999, and will continue with flight lead upgrade training, and other research events into 2000.

The human-centered development approach used by the lab is similar to the process described by Norman (1998) and by Jensen, Boyle, & Fuller (in press). This is a developmental process that starts with a focus on user needs. The simulation testbed technologies are developed as prototypes that are useable by pilot teams as they come to the lab for MTC exercises. While pilot teams are at the lab for these exercises, researchers conduct focused observations to learn how the individuals and teams function in the testbed. Researchers also meet with pilots and obtain their comments about the system and whether or not it works for them in meeting their learning and performance objectives. Feedback from each exercise is evaluated by an integrated development team and applied to further development of the testbed and the processes that are applied when a team of pilots is involved in a series of DMT exercises.

Overview

The goal of this paper is to describe how we are learning to effectively develop Distributed Mission Training exercises and implement them as an environment that will support day-to-day training. This paper will describe:

1. A brief overview of DMT.
2. The significance of a human-centered "iterative" approach in developing DMT training technologies and systems at AFRL.

3. DMT exercises that have been conducted at AFRL and summarize the feedback that has been obtained.
4. Recommendations that may help guide the implementation of DMT at various sites. These recommendations will include guidance for using a human-centered approach towards the development of individual support systems, human interfaces, and training programs.

A BRIEF OVERVIEW OF DISTRIBUTED MISSION TRAINING (DMT)

The concepts behind DMT have been around for a number of years (Alluisi, 1991; Hapgood 1997). Implementation of these technologies has rapidly accelerated because it is getting increasingly difficult for the Air Force to train properly, particularly at the high-end of the training spectrum. General Richard E. Hawley, Commander of the United States Air Force's Air Combat Command, has indicated that current resources and training methods limit the Air Force's ability to prepare warfighters for the complexity of contemporary military operations (Hawley, 1997). He has described DMT as a "system of linked, high fidelity simulators that will allow our combat crews to train more effectively for the increasingly complex combat environment to which we commit them every day." (Hawley, 1998).

DMT will become a simulation network capable of providing participants with real-time team training and mission rehearsal capabilities in synthetic battlefield environments. This network is being developed in incremental stages. The first steps have been taken with the establishment of two F-15C MTCs and one Airborne Warning and Control System (AWACS) MTC. An F-16 MTC is scheduled to join the DMT network in August of 2001. The long-term goal is to provide MTCs for many combat air forces in the United States within the next few years with capabilities to create realistic battle scenarios that enable participants to enhance their analytical and decision-making skills.

A HUMAN-CENTERED DEVELOPMENT APPROACH TO DMT

At AFRL, it has been our experience that meaningful user involvement is critical to the successful development of any training system. The most effective structure to bring people together in support of this effort has been the integrated development team (IDT). An effective IDT requires that user input be the core that defines the needs and forms the basis for a rapidly evolving prototype system. The DMT testbed has been developed through a careful integration of technology with input from users, engineers, researchers, and others. It represents an alternative to design and development processes that often leave out the end users (in this case, the warfighters) and restrict creativity, flexibility, and timeliness.

Norman (1998) describes how products developed from lists of user demands often fail when they are integrated into the work environment. He suggests that failures occur because the actual customers and their needs are different from the focus groups. Further, the design process is often a linear sequence of operations that inhibits interactions among members of the team. While Norman's research focused on consumer systems such as office computers and videotape recorders, Polzella, Hubbard, Brown, and McLean (1987) discovered that many of the advanced instructional features that had been incorporated into Air Force flight training simulators were unwanted and unused when these systems were installed at training squadrons. Jensen et al. (in press) contend that technologically based aircrew training systems often fail because of a linear approach that leaves the user out of the design and development loop. They point out that by the time a device or solution is fielded, there is a high degree of probability that it will not meet the targeted objectives. The reason is that training problems are not static, but dynamic, and the user's needs have probably evolved or changed since they were initially articulated. When design, development, and evaluation occur in this human-centered environment, the potential solution emerges like an expanding core from the center of a development / evaluation spiral.

Developing Effective DMT Missions and Sorties

Since DMT is new and just emerging, there is considerable research and development that needs to be done about how to manage and utilize this new resource. Below is a partial list that represents some of the areas that need to be researched to make the best use of DMT.

- Determine how best to structure DMT training events.
- Develop DMT systems that are designed to enhance training effectiveness.
- Determine how to correlate DMT experience with flight training requirements.
- Develop guidelines for the operation of the MTCs and the supporting organizations.
- Determine the critical command and control elements that need to be employed during DMT exercises.

- Develop DMT guidelines for high-end individual, team, and inter-team combat skills.
- Establish expert model behaviors for warfighter and team training exercises.

DESCRIPTION OF DMT EXERCISES CONDUCTED AT AFRL

The lab's design team has used DMT training exercises to observe pilot teams as they fly a variety of increasingly complex combat missions. After each training exercise, observation data and user feedback have been analyzed to determine areas of strength and weakness. This information has then been applied to improve and / or redesign the scenarios, procedures, and systems for the next exercise. The goal of these exercises is to identify and document how DMT systems can be designed and used most effectively to enhance readiness.

RoadRunner '98

This exercise involved F-16, F-15, and A-10 pilots along with AWACS air weapons controllers in a composite force exercise that was conducted in July of 1998. The exercise lasted five days and involved nine missions during the week. Participants flew two missions each day. Each mission began with a briefing by a flight leader and intelligence officer. This was followed by the mission sorties, which involved four-ship flights that lasted up to one hour. The sorties were followed by a debriefing session that was supported by a mission playback system.

MTC Air Combat Evaluation

This exercise, conducted in early 1999, involved F-16 pilots and AWACS air weapons controllers in a series of increasingly complex missions. Missions focused on 4 v 4 and 4 v X air-to-air scenarios, force protection, and surface attack tactics. The exercise lasted five days and involved up to nine missions during the week. Participants flew two missions each day. As in RoadRunner '98, each mission included a briefing by the flight lead, the mission sorties, and a concluding debrief that was supported by a mission playback system.

Flight Lead Upgrade Training Research

Operational F-16 pilots attend a one-week DMT exercise that focuses on the skills that have been most difficult for pilots to master as they go through the Flight Lead Upgrade (FLUG) course. The objective is to provide DMT training to complement the aircraft training syllabus and to reduce rates of rides that must be repeated as pilots work through their FLUG course.

Experience-Level Research

In conjunction with the FLUG training exercises, additional teams of F-16 pilots from other units are attending the exercise sessions. Teams have come from the Iowa, Colorado, and the New Mexico Air National Guard. Efforts are being focused on how to most appropriately train pilots at different levels of experience such as mission-ready wingman, flight leaders, mission commanders, and instructor pilots.

Data Collection

During these exercises, data were collected using several instruments and methods. The instruments included:

- Surveys administered at the beginning and end of a DMT training week.
- A pilot feedback form that was completed at the conclusion of each mission's debrief.
- Mission performance evaluations completed by a squadron pilot and a laboratory subject matter expert.
- Interviews with participants during and after training exercises.

F-16 Training and DMT Surveys. Pilots were asked to complete two surveys. The first was given at the beginning of the week and asked them to rate the effectiveness of their current F-16 training for a number of mission tasks and skills. Pilots were asked to complete the same survey at the conclusion of the week, but they were asked to rate the effectiveness of DMT for training the same tasks and skills. The results were compared to determine what tasks or skills are best taught through live flying and what tasks or skills are well suited for DMT (see Table 1). These data show that tasks that emphasize out-of-the-cockpit visual cues and aircraft handling are best trained in the aircraft. The data also show that performance for tasks that emphasize multi-ship employment opposed by multiple enemy threats can be improved through DMT exercises. These tasks, particularly four versus many Dissimilar Air Combat Tactics (4 v X DACT), are infrequently practiced in squadron training due to cost and airspace restrictions. Specific skills that are enhanced by DMT experience include radar mechanics, communication in accordance with standards, situation awareness, and decision making.

Table 1. A listing of tasks and skills that pilots rated as more effectively trained in the DMT environment or in current aircraft training.

Tasks and Skills More Effectively Taught in DMT / MTC	**Tasks and Skills More Effectively Taught By Flying Training**
4 v X employment	Basic fighter maneuvers
Rules of engagement	Air combat maneuvering
Commit procedures	Tactical formation
Air intercepts	Gun employment
Radar search discipline	Pre-merge missile defense
Targeting / sorting	Post-merge tactics
Work with AWACS	Mutual support
AIM-120 employment	Visual lookout
Force protection tactics	Basic surface attack
Surface-to-air defense	Visual missile employment

RoadRunner 98 incorporated several types of air-to-surface and air-to-air missions. Based on data from these training effectiveness surveys, DMT research exercises at AFRL/HEA following RoadRunner 98 have reduced emphasis on F-16 air-to-surface missions. Survey results and participant feedback show that these missions are well trained in the aircraft and that performance on tasks such as navigation and ordnance delivery are not likely to benefit from additional DMT experience. Instead, DMT exercises following RoadRunner 98 have focused on multi-ship, multi-bandit, air-to-air missions and on the air-to-air components of surface attack missions. These missions are infrequently trained in aircraft and are well suited to the MCT.

Pilot Feedback Forms. Each pilot completed a feedback form at the conclusion of each debrief. They were asked to comment on how well they were able to achieve their briefed objectives, identify effective attributes about the mission, and make suggestions for improvement. Data from participant feedback forms have been of great value in identifying flaws in simulation fidelity particularly when the simulation requires interactions among independently developed systems. During the RoadRunner 98 exercises, the F-16 cockpits at AFRL/HEA could be engaged by airborne threats from two different computer-generated forces models and from virtual MiG-29s flown by aggressor pilots. Each engagement involved interactions among aircraft models, radars, radar warning systems, missiles, and countermeasures. While the basic operation of these systems was nearly always valid, the details were not. Data from pilot feedback helped the design team identify and eliminate many of these problems. Participant feedback from both pilots and AWACS controllers stressed the importance of mission replay systems to support debrief. The debrief system at AFRL/HEA provides synchronized replay of each pilot's radar screen together with a plan-view (map) display of the engagement (Crane, 1999b). Pilots and controllers report that this system helped them to reconstruct the mission, identify errors, and improve their situation awareness. A near-term need identified from these data is an improved system for distributed mission briefing and debriefing.

Team Performance Evaluations. Team performance gradesheets were developed for the MTC Air Combat Evaluation. These forms provided a tool for a fifth team member (usually an instructor pilot) and a subject matter expert to rate the team performance on a number of pre-established criteria. Evaluation forms were developed for each of the major types of missions, including: 2 v 2, 4 v 4 Defensive Counter-Air (DCA), 4 v X Continuous DCA, Force Protection, Offensive Counter-Air, and Surface Attack Tactics (SAT). Performance of the team was evaluated for the following briefing, mission execution, and debriefing.

The structure of the MCT Air Combat Evaluation was such that pilots began with 2 v 2 engagements, then progressed to a series of 4 v 4 air-to-air scenarios. The complexity of missions was increased by adding increasing numbers of bandits in a 4 v X environment. By the third day, the teams were flying continuous 4 v X missions in which they were flying against from 6 to 20 bandits. These represented the most challenging missions they faced during the week.

Analysis of the team performance ratings show that as the level of mission complexity increased, performance ratings initially went down. This trend continued until the third day, when performance was rated lowest. By this time, most teams had experienced about 10 or 11 major engagements. Though the number of bandits did not increase after the third day, performance was rated dramatically higher. This trend was probably most pronounced for the key assessment of "Air Intercepts" (see Figure 1).

More detailed analysis of the evaluation data, instructor comments, and discussions between squadron instructors and laboratory subject matter experts uncovered the reasons behind this pattern of results. The initial 2 v 2 engagements were modeled on current squadron training and presented few challenges for participants. Performance then declined as pilots and controllers executed 4 v 4 and 4 v X engagements.

Pilots experienced difficulties at first in using their radars to target and sort multiple maneuvering aircraft. Pilots and controllers also had difficulties in using standard terminology in radio communications to efficiently and effectively share information. However, as pilots and AWACS controllers gained experience, their performance improved rapidly.

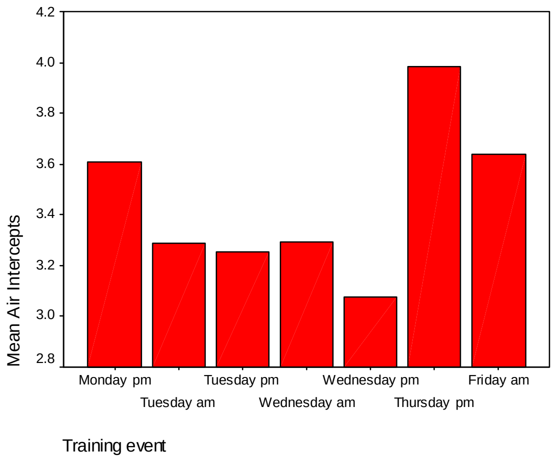

Figure 1. Mean instructor ratings for team performance over seven successive DMT training events.

Data from individual interviews during and after training weeks helped to identify mission scenarios and systems that contributed to improvements in mission performance. Two examples of changes that were implemented as a result of user input were: (a) real-time instructor control of scenarios, and (b) repeating missions morning and afternoon. During the RoadRunner 98 exercise, mission scenarios were created by laboratory subject matter experts in cooperation with squadron instructor pilots. However, once the scenarios were programmed, there was little control over the events with a mission. Since the results of RoadRunner 98 demonstrated that four-ship air-to-air engagement was a major training objective, the design of a DMT session was modified to incorporate three to five, separate 4 v 4 or 4 v X engagements in an hour. The squadron instructor pilot observed each mission from the operator's console and was given the option to stop and restart a scenario, repeat a scenario, or to go on to a more complex scenario. In one case, the instructor pilot had his team repeat one scenario three times. However, by the end of the week instructors were requesting the most complex scenarios available. A second pilot request was that teams should fly the same missions during their morning and afternoon sessions. When asked why they wanted this, the pilots replied that the last part of any debriefing is to draw lessons learned from a mission and to devise plans for how they would fight the mission the next time. However, next time may be months in the future. In DMT, the pilots and controllers can fight the same mission later in the day and implement the lessons learned. A second advantage of this procedure was developed entirely by the participants. In the morning mission, an experienced commander would lead the flight. In the afternoon, a less experienced pilot would be given the opportunity to brief, lead, and debrief the flight. Opportunities to lead air-to-air missions are unfortunately rare and DMT provided less experienced pilots with valuable leadership experience.

Interviews with participants. Pilots were informally interviewed by laboratory subjects during exercises with more formal telephone interviews within a few weeks afterwards. One lieutenant who had less then 300 hours in the F-16 commented that his entire perspective changed during the week he was engaged in flying the testbed missions. He said that he had almost no experience in 4 v X air-to-air environments. As he sat in his cockpit during the first few engagements (early in the week), he had a mental image of what was transpiring with the entire team. Yet, when he attended the debriefing, the digital playback that he saw on the screen showed a completely different picture than what he had created in his mind. As the week went on with more missions and more time spent viewing replays, his understanding of the air-to-air environment grew rapidly. He said that by the end of the week, when he went into the debriefing, the mental image he had was very similar to the images he saw during the digital playback of the mission.

The experience of this pilot was validated when his unit flew their last mission of the week. The instructor pilot with the team decided to give the two least experienced pilots (both lieutenants with less than 300 hours in the F-16) the opportunity to act as flight leads. One acted as the four-ship flight lead while the other was the two-ship (element) lead. They performed all activities of the regular flight lead, including planning, briefing, leading, and de-briefing the mission. While they led this mission, their team performed at or above the levels they had performed for other similar missions during the week. The day after they completed their week at AFRL/HEA, they returned to their unit and flew a four-ship exercise in which one of the lieutenants was permitted to fly as a flight lead for the live flight. The lieutenant's performance on this mission was rated well above expectations for a pilot with so little experience.

Here are sample comments from follow-up interviews.

Pilot #1. "Overall, all pilots felt this training was very positive and definitely worthwhile. The DMT offered some training opportunities that are extremely difficult to get in the air…..The biggest plus was the DMT was an excellent tool to practice 4 v X employment. We employed 'grinder' tactics for most of the week and the training was outstanding. The interface with AWACS was excellent and the learning curve from both sides was steep. The ability to fly a true 4 v X, with X often being much more than 4 was great and something that most units rarely get to do. Flying against a variety of bandits (MiG-29, Su-27, MiG-23) was another huge plus and the VID [visual identification] training was fairly realistic. It was also nice to actually get "real world" spikes and be able to see missile launches when we were targeted. The DMT was a great tool to work on comm, radar mechanics, and game plan execution. We also liked having unlimited "airspace" to work in where borders, altitudes, and airspeed weren't a factor. Finally, the debrief facilities were excellent and enabled us to really glean the appropriate lessons learned."

Pilot #2. "Let me state briefly that the simulator was the best I have seen to date and the realism was as close to actually being in the cockpit …. You get instant feedback on the execution of your tactics and how well you communicated …. The presentations I saw were as real as I've ever seen flying the F-16 in 4 v X or LFE's [Large Force Exercises]…. I believe in the long run this SIM will have tremendous value in areas such as Crew Resource Management, Operational Risk Management and (will) reduce accidents associated with large force exercises."

AWACS Commander. "This is really going to save me lots of money. It is going to give me realistic training and decrease the time it is going to take me to experience a guy who is ready to go out on the road by himself. It will make us a lot more efficient."

RECOMMENDATIONS FOR THE IMPLEMENTATION OF DMT

DMT systems and exercises at AFRL/HEA are being developed by an integrated design team that incorporates warfighters, engineers, behavioral scientists, and subject matter experts. Systems and training events have been greatly modified since our first DMT exercise in July 1998. Data from RoadRunner 98 and subsequent exercises have been used to: (a) identify high payoff tasks and missions for DMT, (b) design and configure DMT systems, and (c) develop effective and efficient training procedures. The following recommendations are offered.

Four-Ship Simulators

Use four-ship simulators equipped with full field-of-view visual display systems together with high-quality, computer-generated forces to develop the broad range of individual and team skills needed for effective multi-ship, multi-bogey, air-to-air combat. A four-ship simulation site provides a unique opportunity for a flight to brief, practice, and debrief critical setups that are not often available during normal flying conditions. This type of setup provides:

1. The flight team with the ability to practice multiple setups in a short period of time.
2. An instructor pilot with the capability to analyze a flight and provide immediately feedback (if necessary).
3. Each member of the flight team with help in the development of situation awareness by providing feedback of the entire flight arena via debrief playback systems that can be accessed within minutes after flying a scenario.
4. The instructor pilot or flight lead with the ability to gradually increase levels of complexity based on the needs and abilities of the four-ship flight team members.
5. Opportunities for less experienced pilots to gain leadership experience.

Debriefing Capabilities

The debrief is critical to the effective acquisition of individual and team skills. The debriefing system requires playback of the missions flown incorporating an overall view of the mission together with information from each participant's aircraft. The playback system should enable the users to zoom in and out, adjust the point of reference, pause, and visually scan forward and reverse to enable the user to quickly identify a critical spot in the mission that needs to be reviewed. A pressing near-term need is the capability for distributed mission briefing and debriefing so that participants at multiple MTCs may work together to improve team and inter-team skills.

Conclusion

DMT represents a new training medium. The integrated design team at AFRL/HEA is learning about the strengths, shortfalls, and opportunities for DMT by conducting frequent exercises. Since this technology is evolving so rapidly, a human-centered development approach offers a logical means for involving users, developers, subject matter experts, technicians, and administrators in determining how best to use these new capabilities.

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