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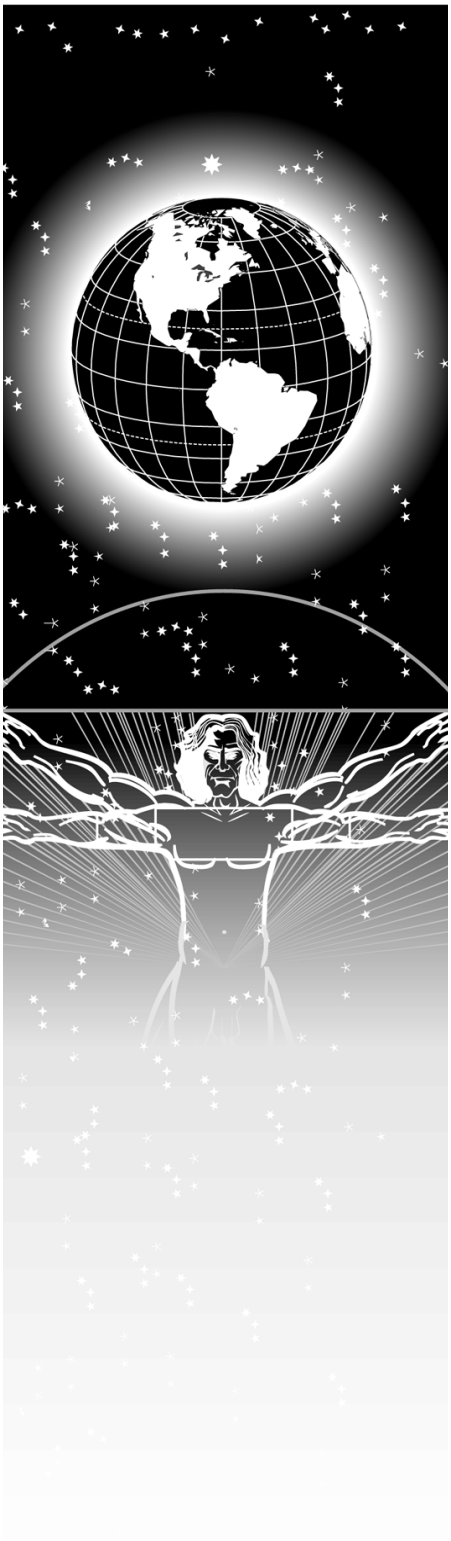

UNITED STATES AIR FORCE RESEARCH LABORATORY

ROADRUNNER '98: TRAINING EFFECTIVENESS IN A DISTRIBUTED MISSION TRAINING EXERCISE

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14. ABSTRACT
RoadRunner '98 was successfully conducted at the Air Force Research Laboratory, Mesa, AZ; the Theater Air Command and Control Simulation Facility, Kirtland AFB, NM; and the 522d Air Control Wing, Tinker AFB, OK, from 13-17 Jul 98 to evaluate the training effectiveness of Distributed Mission Training (DMT) systems. RoadRunner '98 combined virtual (man-in-the-loop) training events at DMT platforms with computer-generated constructive models. The systems were integrated over a wide geographic area through secure networks carrying voice, video, data, and image information. The objectives of RoadRunner '98 were to: (a) demonstrate the state-of-the-art DMT technologies, (b) identify the strengths and weaknesses of these technologies, (c) explore how to best use this new training environment for desired and enhanced levels of team training effectiveness, and (d) develop a research and development agenda for the future. This report describes the RoadRunner '98 DMT system, the training missions included in the exercise, and results in terms of mission performance and feedback from participants. DMT strenths and areas for improvement are discussed together with recommendations for future training research exercises.

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Computer-generated constructive models; Distributed Mission Training; DMT; Mission performance; Networking; RoadRunner '98; Training; Training effectiveness; Training research exercises

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PREFACE

RoadRunner '98 was a training research exercise sponsored by the Air Force Modeling and Simulation Office (USAF/XOC). This report documents work performed by the Air Force Research Laboratory, Human Effectiveness Directorate, Warfighter Training Research Division (AFRL/HEA) in Mesa AZ. This effort was conducted under Work Unit 2743-B2-05, Distributed Mission Training. The Laboratory Work Unit Monitor was Maj Justine Good; the Laboratory Project Scientist was Dr Peter M. Crane.

The authors gratefully acknowledge assistance in preparation of this technical report from Linda Elliott, Herbert Bell, Robbie Robbins, Don Smoot, Paul Nielson, J. D. Dennison, Maj Dennis Gleason, Glenn Cicero, Bart Raspotnik, and Elizabeth Casey. We further express our thanks to the many individuals and organizations who cooperated in the development and conduct of the RoadRunner '98 exercise with special thanks to the participating warfighters.

EXECUTIVE SUMMARY

RoadRunner '98 was a research exercise designed to assess the technical feasibility and training potential of Distributed Mission Training (DMT). RoadRunner '98 was sponsored by the Air Force Modeling and Simulation Office (USAF/XOC) and conducted by the Air Force Research Laboratory, Warfighter Training Research Division (AFRL/HEA) and the Theater Air Command and Control Simulation Facility (TACCSF). DMT is an emerging training concept in which warfighters will use advanced, real-time simulators located around the world to conduct mission training in a virtual battlespace. As envisioned by Air Combat Command (ACC), DMT will complement current squadron training and large-force exercises by providing additional experience in performing tasks and missions that are infrequently practiced or highly constrained. Using DMT, warfighters will be able to interact with each other and with computer-generated forces to conduct composite force missions unconstrained by limitations of cost, safety, and security. The objectives of RoadRunner '98 were to determine whether state-of-the-art DMT technologies were capable of supporting composite force training exercises over a wide area network and to validate a research approach for conducting DMT training effectiveness evaluations. This report describes how the RoadRunner '98 exercise was conducted, the data that was collected, and the successes and shortfalls in meeting exercise objectives.*

In RoadRunner '98, F-15 and F-16 fighter pilots and Airborne Warning and Control System (AWACS) air weapons control teams flew seven training missions from locations in Arizona, New Mexico, and Oklahoma during the period of 13–17 Jul 98. Data collected were measures of mission accomplishment, instructor ratings of team performance, and participant critiques and recommendations. All RoadRunner '98 missions were completed as planned without major difficulties or delays. Results show that team performance on composite force missions improved during RoadRunner '98, pilots and AWACS crews were able to successfully complete their missions, and all participants rated DMT as having significant training potential. Participants identified several areas for improvement, notably, visual display systems, computer-generated forces, and interactions among simulated entities. Data from RoadRunner '98 also show that the perceived training value of participating in DMT exercises depends on both the capability of DMT systems to support a particular mission or skill and the availability of aircraft training for that mission or skill. Recommendations are offered for further development of DMT systems and for future DMT exercises.

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* Additional information on the RoadRunner '98 exercise is available in a classified report: Cicero, G. D. (1998). *Simulated Threat Performance Observations for RoadRunner '98*(U). (AFRL-HE-AZ-TR-1998-0100) Mesa, AZ: Air Force Research Laboratory.

ACRONYMS AND ABBREVIATIONS

AAA	Antiaircraft Artillery
ACC	Air Combat Command
ACC/DOT	Air Combat Command Deputy of Operations for Training
ACM/ACT	Air Combat Maneuvering / Air Combat Tactics
AACS	Airborne Air Control Squadron
ACS	Air Control Squadron
ACW	Air Control Wing
AFIWC/SAM	Air Force Information Warfare Center Advanced Combat Simulations Division
AFRL	Air Force Research Laboratory
AFRL/HEA	Air Force Research Laboratory, Warfighter Training Research Division
ATES	Automated Threat Engagement System
ATO	Air Tasking Order
AWACS	Airborne Warning and Control System
BFM	Basic Fighter Maneuvers
Blue	Friendly forces
Bogey	Unidentified, potentially hostile aircraft
BSA	Basic Surface Attack
BVR	Beyond Visual Range
CAP	Combat Air Patrol
CAS	Close Air Support
DACT	Dissimilar Air Combat Tactics
DART	Display for Advanced Research and Training
DCA	Defensive Counterair
DIS	Distributed Interactive Simulation
DMPI	Designated Mean Point of Impact
DMT	Distributed Mission Training
ECCM	Electronic Counter Countermeasures
ECM	Electronic Countermeasures
FAC	Forward Air Controller
FEBA	Forward Edge of the Battle Area
FS	Fighter Squadron
FW	Fighter Wing

GCI	Ground-controlled Intercept
HARM	High-speed Anti-Radiation Missile
HUD	Head-up Display
IADS	Integrated Air Defense System
IANG	Iowa Air National Guard
IG	Image Generator
M2DART	Mobile Modular Display for Advanced Research and Training
MDT2	Multiservice Distributed Training Testbed
MTT	F-16 Multitask Trainer
NAWC-TSD	Naval Air Warfare Center Training Systems Division
OCA A-A	Offensive Counterair – Air to Air
OCA A-G	Offensive Counterair – Air to Ground
P_k	Probability of Kill
RAP	Ready Aircrew Program
Red	Enemy forces
Red Flag	Large-force exercise conducted in Nevada
RWR	Radar Warning Receiver
SAM	Surface-to-Air Missile
SAT	Surface Attack Tactics
SEAD	Suppression of Enemy Air Defenses
SEAD-C	Suppression of Enemy Air Defenses using Conventional ordnance
SGI	Silicon Graphics, Inc.
SMS	Stores Management System
SPINS	Special Instructions
TACCSF	Theater Air Command and Control Simulation Facility
TARGET	Targeted Acceptable Responses to Generated Events or Tasks
TEWS	Tactical Electronic Warfare System
TOM	Teamwork Oriented Measurement Scale
TWS	Track While Scan
USAFE	United States Air Forces in Europe
USAF/XOC	Headquarters U. S. Air Force Modeling and Simulation Office
White Cell	Exercise planning and preparation team
WTT	F-15 Weapons and Tactics Trainer

ROADRUNNER '98: TRAINING EFFECTIVENESS IN A DISTRIBUTED MISSION TRAINING EXERCISE

INTRODUCTION

RoadRunner '98 was an Air Force exercise designed to assess the state of the art in Distributed Mission Training (DMT) for aircrew training. DMT is an emerging training concept in which warfighters enter into a synthetic battlespace using live, constructive, and virtual simulations. In the synthetic battlespace, warfighters are able to execute complex, composite force missions unconstrained by issues of cost, safety, and security that restrict current live exercises. Unlike previous multiplayer simulation studies that were conducted to demonstrate a proof-of-concept or to evaluate technology, the intent of RoadRunner '98 was to assess the effectiveness of DMT by bringing operational pilots and battle managers together for a series of composite force missions. The products of RoadRunner '98 are an assessment of the training potential of DMT, recommendations for best use of current DMT systems, a description of lessons learned, and recommendations for improving DMT systems. This report describes and summarizes the measures of training effectiveness collected during the RoadRunner '98 DMT exercise and recommendations for improving training effectiveness.

RoadRunner '98 Overview

Development and conduct of RoadRunner '98 was a combined effort of many organizations. RoadRunner '98 was sponsored by the Air Force Modeling and Simulation Office (USAF/XOC) with the Air Force Research Laboratory, Human Effectiveness Directorate's Warfighter Training Research Division (AFRL/HEA) serving as program managers and the Theater Air Command and Control Simulation Facility (TACCSF) as systems integrators. Extensive support was received from the Training Office at Air Combat Command's Deputy for Operations (ACC/DOT), the Air Force Information Warfare Center's Advanced Combat Simulations Division (AFIWC/SAM), the Airborne Warning and Control Systems (AWACS) training office at the 552nd Air Control Wing (ACW), the 133rd Airborne Air Control Squadron (AACS) of the Iowa Air National Guard (IANG), and the Naval Air Warfare Center's Training Systems Division (NAWC-TSD). The warfighters who participated in RoadRunner '98 were operational pilots from the 27th Fighter Wing (FW), Cannon AFB NM; the 185 and 132 FWs of the IANG; the 33rd Fighter Wing, Eglin AFB FL; United States Air Forces in Europe (USAFE); and weapons directors and air surveillance technicians from the 552 ACW, Tinker AFB OK.

The goal of DMT is to provide home station training for all warfighters. During RoadRunner '98, only AWACS had on-base simulation systems capable of participating in a DMT exercise. F-16 pilots used AFRL/HEA's system of four F-16C Multitask Trainers (MTTs) located in Mesa AZ, while F-15 pilots used TACCSF's system of four Boeing Weapons and Tactics Trainers (WTTs) at Kirtland AFB NM.

During the period of 13–17 Jul 98, teams of warfighters flew one familiarization mission plus seven composite force missions over a synthetic Red Flag Training Range. Each mission was executed over a secure, wide-area network using Distributed Interactive Simulation (DIS) communications protocols. In these missions, pilots and AWACS teams interacted with virtual

and constructive, i.e., computer-generated, forces including friendly and enemy fighters, helicopters, and ground vehicles, plus enemy surface-to-air threats. Five of the seven composite force missions were offensive air-to-surface, one mission was defensive air-to-air, and one was Close Air Support (CAS). The intent of RoadRunner '98 was to provide operational warfighters with the opportunity to experience DMT using state-of-the-art systems. Based on their experience, warfighters were asked to identify the technical successes and shortfalls in these systems and to assess the potential for DMT to improve future Air Force training.

Multiplayer Simulation Background

Although flight simulation has been a part of aircrew training since the Link "Blue Box" instrument simulators of World War II, such training was traditionally limited to training basic procedural and psychomotor skills. This limited training reflected the capabilities of simulator technology that could not support high-fidelity, individual training for tasks other than basic skills. As simulation technology improved, however, the idea was proposed that multiple simulators could be linked to allow pilots and other warfighters to conduct multiplayer engagements in a virtual battlespace (Hapgood, 1997). By the mid-1980s technology advanced to the point that it was possible to interconnect simulators and conduct team training. The first example of such training was the SIMNET project in which a number of tank simulators were interconnected to provide collective training (Alluisi, 1991). Based on the success of the SIMNET program, the Air Force Research Laboratory embarked on a science and technology program to develop simulator-based training technologies and methods that would afford aircrews the same training opportunities that SIMNET afforded the ground forces.

One of the first research studies which examined aircrew training in a team context took place at the McDonnell-Douglas's F-15 simulator complex (Houck, Thomas, & Bell, 1991). Mission-ready F-15 pilots and air weapons controllers received advanced air combat training as three-member teams. The two pilots flew high-fidelity F-15 cockpits located in 40-ft domes while a Weapons Director operated a high-fidelity display and communication system. A full spectrum of simulated air combat missions were flown against a variety of enemy forces which were either constructive models or virtual aircraft flown by pilots from small player stations. Teams performed their normal mission planning and premission briefing. They also debriefed as usual using an instrumented debriefing system that provided them with a plan view display of the gaming area, full cockpit instrumentation, voice communication, and detailed information on weapons effectiveness. Participant feedback and measures of combat effectiveness showed that mission performance improved with training and that the warfighters were generally positive about the experience. They rated simulator-based combat training as superior to their local flying training for some combat tasks.

Based on the success of the air combat training program at McDonnell-Douglas, a combat mission training simulation testbed was established at the Air Force Research Laboratory's facility in Mesa, AZ. This facility has been used to conduct both engineering development and training effectiveness research. One example is the Multiservice Distributed Training Testbed (MDT2) training research project that was conducted using assets from all four services at locations across the country. As part of the MDT2 project, a wide-area training network was established that linked Air Force flight simulators in Mesa AZ, and Navy flight simulators at Patuxant River MD, with Army tank simulators at Ft. Knox KY, and a Marine fire support simulator in San Diego CA (Bell, et al., 1996). All these heterogeneous virtual

simulators interacted within a common synthetic environment that represented the National Training Center at Ft. Irwin CA. These virtual simulators were integrated with a manned Tactical Operations Center, staffed by appropriate Army and Air Force personnel. In addition, Modular Semi-Automated Forces provided constructive friendly and enemy forces needed for a realistic battalion-level engagement. During MDT2, two Air Force F-16 simulators provided close air support to a battalion task force with support from a Marine forward air controller (FAC) located on the ground and a Navy airborne FAC flying an OV-10 simulator. Each simulator communicated using DIS protocols and shared a common battlespace. This common synthetic environment incorporated 11 virtual simulators and over 100 computer-generated entities to provide tactical combat training to 33 individual warfighters. Communication and coordination skills all improved by significant margins as the warfighters from different services gained experience working together. As these communication and coordination skills improved, the ability to effectively execute close air support procedures increased and the number of successful weapons deliveries and the number of enemy tanks destroyed increased.

Attitude questionnaires and interviews administered to MDT2 trainees from each service showed considerable enthusiasm for this type of training. Many of the warfighters felt that it was the best training they had ever received in performing such difficult joint force training. Their attitude is perhaps best summed up by the comments of the battalion commander who said it was the most and best close air support training he had received in his nearly 20-year career.

DMT as Central Component of Future Air Force Training

Multiplayer simulation systems have been used by the U. S. Army for armored vehicle training and by the U. S. Navy for shipboard combat information center training. Outside of the laboratory, however, real-time simulators have been used in the Air Force largely for individual skills training (Bell & Waag, 1998). Due to the peacetime training constraints plus increased operations and personnel tempo, the Air Force has undertaken a program of placing DMT assets around the world linked into a common synthetic battlespace (Hawley, 1997, 1998). An objective of AFRL/HEA's DMT research program is to identify the systems and capabilities necessary to support these training goals.

Measurement of Team Performance

Air Combat Command's (ACC) concept for DMT is to provide both team skills training and interteam skills training. Team skills are defined as, "the collective skills needed to perform missions… Teams are usually composed of a single type of weapons system from the same unit." Interteam skills are, " the composite skills required to perform missions," where inter-team relationships, "are based on temporary assignment of teams from several units to a single composite force package," (ACC, 1998, p. 6). Currently, training requirements for these skills are defined by ACC's Ready Aircrew Program (RAP) which specifies the minimum number of training sorties and events that must be accomplished by each pilot to maintain combat mission-ready status. Proficiency for individual pilots is assessed by an instructor or flight leader, however, there are few metrics for assessing proficiency in team or interteam skills. An objective of AFRL/HEA's DMT research program is to assist ACC's implementation of DMT by developing metrics for assessing team performance and for relating team skills to measures of mission accomplishment. RoadRunner '98 incorporated candidate measures of team performance.

Objectives of RoadRunner '98 Exercise

The specific objectives for RoadRunner '98 were to:

Demonstrate DMT capabilities necessary for combat mission training. The first objective of the RoadRunner '98 exercise was to create a synthetic battlespace using state-of-the-art systems and to assess each system's capability to support DMT. To achieve this objective, warfighters compared their experience in RoadRunner '98 to their previous experiences and identified DMT systems that successfully supported mission accomplishment, systems that detracted from mission accomplishment, and systems that demonstrated only limited success.

Validate a research approach for DMT training effectiveness studies. The second objective of RoadRunner '98 was to support future DMT research efforts. To achieve this objective, squadron instructors and other subject-matter experts evaluated team performance using grading forms designed to assess team performance. Scores on these forms, together with measures of mission accomplishment, were analyzed to determine whether warfighter proficiency was affected by experience using DMT and to identify team processes that could be enhanced through DMT.

RoadRunner '98 Systems and Approach to Training

RoadRunner '98 incorporated geographically dispersed warfighter-in-the-loop (virtual) simulations and computer-generated (constructive) simulations into a virtual battlespace using DIS communications protocols and high-bandwidth data links. Following is a brief description of RoadRunner '98 systems, training scenarios, and procedures.

Systems

Network and locations. Virtual simulations in RoadRunner '98 were located at AFRL, Mesa AZ (F-16 and A-10), TACCSF (F-15 and virtual red air), and Tinker AFB OK (AWACS). Constructive simulations were located at AFRL (aircraft plus surface vehicles), TACCSF (E-3 AWACS aircraft model), and AFIWC, Kelly AFB TX (surface-to-air missiles [SAMs] and radars). In addition, real-time observation systems linked to the RoadRunner '98 network were located at the Theater Battle Arena at the Pentagon, Arlington VA; the Simulation Analysis Facility, Wright-Patterson AFB OH; and the 133 ACS, Ft. Dodge IA, via the 133 ACS, Phoenix AZ; see Figure 1.

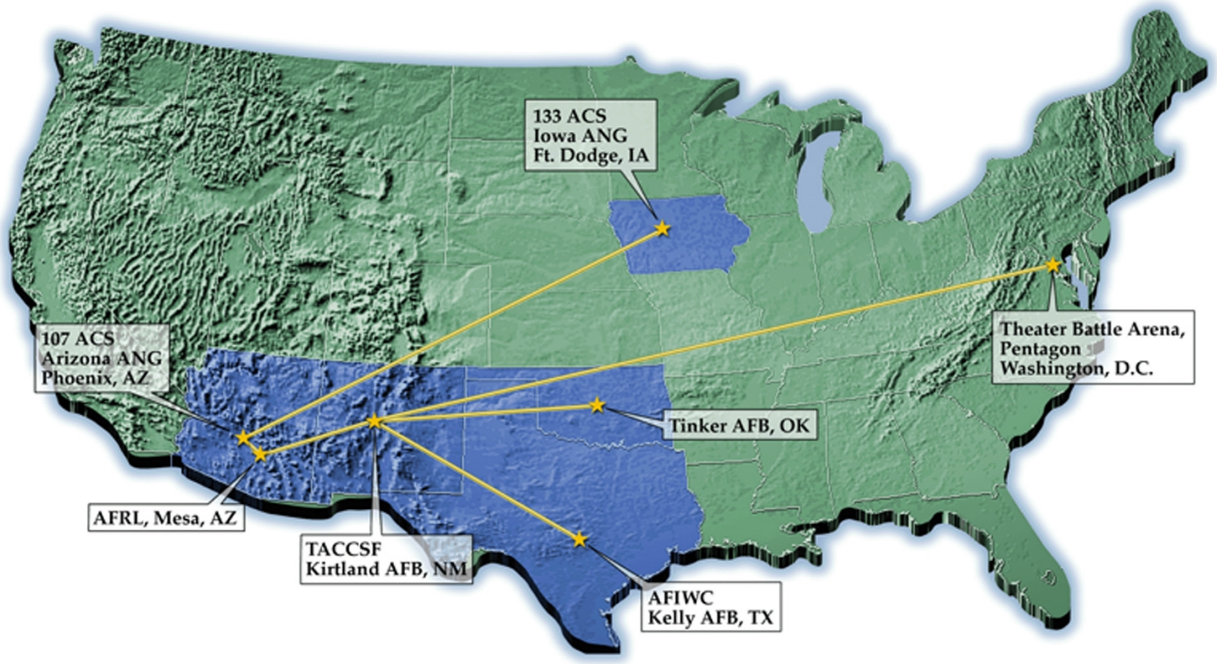


Figure 1. Map of RoadRunner '98 locations

All links in the RoadRunner '98 network were commercial T-1 lines except for the connection from TACCSF to Tinker AFB, which was built around two, conventional telephone lines, and the connection from AFRL Mesa, to Ft. Dodge which was an experimental satellite link. The bandwidth provided by T-1 lines has proven to be fully sufficient in DMT exercises conducted prior to RoadRunner '98. The telephone-line connection to Tinker AFB provided significantly less bandwidth. The data stream was therefore filtered down to only voice communication and aircraft location. While this bandwidth was sufficient to support virtual

AWACS participation, the connection suffered from reliability problems. The satellite link was adequate for observation of RoadRunner '98 missions.

Cockpits and visual displays. One of the virtual cockpits at AFRL Mesa, was an A-10 and four were F-16C, Block 30 MTTs that were developed by AFRL for the Air Force Reserve (Boyle & Edwards, 1991); see Figure 2a. These cockpits were equipped with AFRL's Mobile Modular Display for Advanced Research and Training (M2DART) which is a full-field of view, rear-projection, dome display system (Best, Wight, & Peppler, 1999); see Figure 2b. The M2DARTs provided out-the-window visual imagery combined with the aircraft's head-up display (HUD).

Figure 2. a) F-16 MTT cockpit b) M2DART

Out-the-window, visual imagery was provided to two of the F-16 cockpits from Lockheed-Martin SE2000+ Image Generators (IGs) which utilized polygonized terrain and feature representations augmented with cell texture maps; see Figure 3a. Imagery was provided to the other two cockpits from Silicon Graphics, Inc. (SGI) Reality Monster IGs which used polygonized terrain representations augmented with geo-specific, photo-texture maps. Three-dimensional feature models were inserted into the SGI database only in airfield and target areas; see Figure 3b. Compared to the SGIs, the SE2000+ IGs provided more vertical features which can be discerned at low altitude while the SGIs provided more scene realism when the pilot was flying over 2000 feet above ground level.

The M2DART provides an instantaneous field-of-view greater than 180° with high brightness and contrast and a 360° total field-of-regard using a head-tracking system. Resolution is approximately 4 arc-minutes per pixel. Evaluation studies have demonstrated that this resolution does not allow a pilot to detect, identify, or determine the aspect of other aircraft at realistic tactical ranges. For example, a common tactical formation during ingress would be line abreast with aircraft separated by approximately one nautical mile (1 NM = 6,076 feet). At this distance, an F-16's longest dimension (length) subtends less than eight pixels and the shortest dimension (tail height) subtends less than three. Against a cluttered background, a target model of this size is very difficult to detect. To increase target visibility, aircraft models in the M2DART are replaced by a point light when range exceeds 4,000 feet. This light is colored blue or red to indicate friendly or foe between 4,000 feet and 3 NM and white from 3 NM to 7 NM.

While this system increases detection and identification ranges to acceptable distances, pilots still cannot determine aspect beyond 4,000 feet.

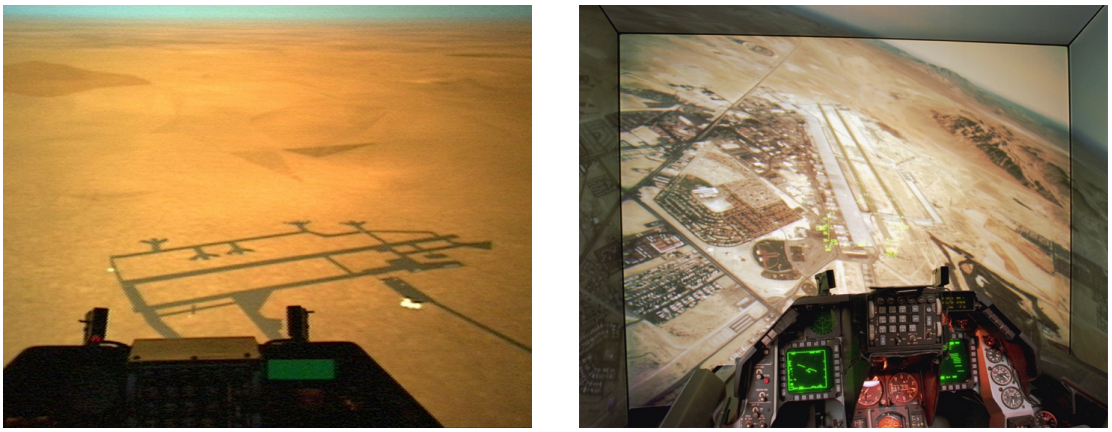


Figure 3. a) SE2000+ sample image b) SGI sample image

The A-10 at AFRL/HEA was equipped with an earlier model DART visual display. This DART did not provide out-the-window visual at the aircraft's 6 o'clock position. Imagery was supplied from a Lockheed-Martin SE 2000.

The four, virtual F-15 cockpits at TACCSF were WTTs. The visual displays on these cockpits consisted of a single CRT that incorporated forward, out-the-window visual imagery and the aircraft's HUD; see Figure 4a. In addition to the virtual F-15s, two virtual MiG-29 red air stations were located at TACCSF supported by a red air controller; see Figures 4b and c. These stations incorporated aircraft instruments and HUD with only a limited visual display. The virtual AWACS stations were full mission trainers located at the AWACS training facility, Tinker AFB OK, and adapted for participation in DMT exercises (see Figure 4d).

Constructive forces. Incorporating computer-generated, constructive forces into a DMT exercise allows virtual players to interact with many friendly, neutral, and opposing players without requiring real-time participation of human-in-the-loop simulators. The limitations of constructive forces are that each constructive model has different strengths and capabilities and that each must be preprogrammed for each scenario. In addition to the constructive AWACS aircraft model, the systems used in RoadRunner '98 were AFRL/HEA's Automated Threat Engagement System (ATES), TacAirSOAR, and AFIWC's Integrated Air Defense System (IADS) (Cicero, 1998).

The ATES constructive forces simulation was developed at AFRL/HEA to support research on multiship training systems (Rogers, 1992; Platt & Crane, 1993). ATES is a blend of several programs from various government agencies and a commercial vendor that can generate synthetic aircraft, ground vehicles, and surface-to-air threats. During RoadRunner '98, ATES provided enemy fighter aircraft, a KC-135 aerial refueling tanker, and ground vehicles. ATES aircraft models are both scriptable and autonomous. Fighter aircraft, for example, can be scripted to assume a combat air patrol (CAP) where they will remain throughout a scenario until either a preset length of time has passed or until an opposing aircraft comes within a preset range. The ATES fighters will then become autonomous and attack using an intelligent flight model that incorporates knowledge of weapons and tactics appropriate for the aircraft type.

ATES fighters used during RoadRunner '98 were MiG-29s and Su-27s armed with AA-10a missiles, and MiG-23 attack aircraft.

a) F-15 WTT

b) Red air pilot

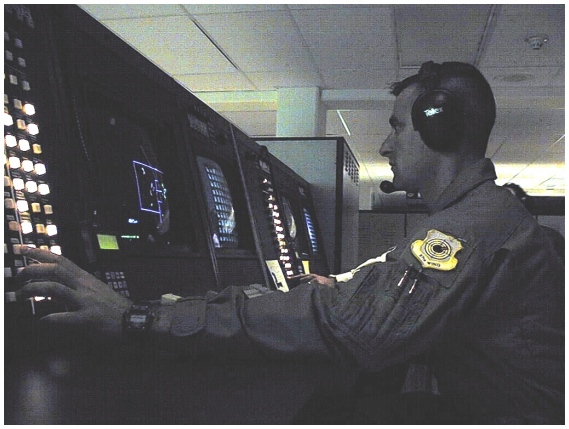


Figure 4. c) Red controller d) AWACS simulator

TacAirSOAR was developed at the University of Michigan and the Information Sciences Institute of the University of Southern California under the Defense Advanced Research Projects Agency's Synthetic Theater of War program (Jones, Laird, & Neilson, 1998). The goal of TacAirSOAR is to develop human-like synthetic entities for populating simulation environments. It accomplishes this by using SOAR architecture to integrate a wide range of intelligent capabilities, including real-time hierarchical execution of complex goals and plans, communication and coordination with humans and simulated entities, maintenance of situational awareness, and ability to accept new orders while in flight. The primary role of TacAirSOAR controlled aircraft in RoadRunner '98 was to enhance the scenario by providing realistic forces flying in strike packages with other computer-generated forces and with manned simulators. TacAirSOAR aircraft used during RoadRunner '98 F-16C Block 50s armed with High-speed Anti-Radiation Missiles (HARMs), F-16C Block 30 strikers, and helicopters.

AFIWC's IADS model provided a basic air defense system consisting of two early warning radars and several SAM batteries. The SAM systems were one SA-2, two SA-6, and three SA-8 sites. Command and control functions were simulated through interactions between the early warning radars and SAM sites.

Control consoles. The simulation control consoles at the various RoadRunner '98 sites provided both an interface for system operators to conduct a mission and an observation station for instructors to monitor team performance.

At AFRL/HEA, the control console incorporated an operator's station, the exercise director's station, and an observer's station for the F-16 instructor pilots; See Figure 5a. The instructor monitored mission progress on a six-screen, video display system which showed the forward, out-the-window view from each of the cockpits together with a plan-view or map-like display of the gaming area showing icons for each entity in the scenario. The sixth video display showed the radar screens from each of the four cockpits; see Figure 5b. The exercise director at AFRL/HEA could communicate with all participants and issue global freeze/unfreeze commands. The exercise director could also communicate privately with the control console operators at the other RoadRunner '98 sites either through a digital voice channel or using a telephone for backup.

<table>
<tr><td rowspan="2">F-16 #1
forward view</td><td>F-16 #1
radar</td><td>F-16 #3
radar</td><td rowspan="2">F-16 #3
forward view</td></tr>
<tr><td>F-16 #2
radar</td><td>F-16 #4
radar</td></tr>
<tr><td>F-16 #2
forward view</td><td colspan="2">Plan view
display</td><td>F-16 #4
forward view</td></tr>
</table>

Figure 5. a) AFRL control console b) Diagram of AFRL console

Control capabilities at TACCSF incorporated repeater screens for AWACS, F-15Cs, and virtual MiGs together with a stealth view of the battlespace. Data filtering and the communications link with AWACS at Tinker AFB were also located at TACCSF. Control capabilities at Tinker AFB were limited to communications systems with TACCSF and local instructor-operator stations.

Debrief systems. Previous research (Bell & Waag, 1998; Berger & Crane, 1993; Houck et al, 1991) has demonstrated that value of mission replay in supporting team debrief. The debrief system at AFRL/HEA supported synchronized replay of a plan-view display together with information from each cockpit (radar screen, HUD, Radar Warning Receiver [RWR], and Stores Management System[SMS]); see Figures 6 a and b. Debrief systems at TACCSF for the F-15 pilots and at Tinker for AWACS teams provided only the plan-view which was presented in map-like format at TACCSF and as an AWACS display at Tinker.

F-16 #1 RWR	F-16 #1 HUD	[not used]	F-16 #3 RWR	F-16 #3 HUD
F-16 #1 Radar	F-16 #1 SMS		F-16 #3 Radar	F-16 #3 SMS
F-16 #2 RWR	F-16 #2 HUD	Plan view display	F-16 #4 RWR	F-16 #4 HUD
F-16 #2 Radar	F-16 #2 SMS		F-16 #4 Radar	F-16 #4 SMS

Figure 6. a) AFRL debrief system b) Diagram of AFRL debrief screens

Training Scenarios

The training scenarios used in RoadRunner '98 were developed by an exercise planning team (white cell) that included subject-matter experts from AFRL/HEA and TACCSF together with intelligence and training officers from participating units. Since all participants in RoadRunner '98 were mission-qualified warfighters, it was not necessary to train basic skills or procedures. Rather, mission scenarios were designed to enhance skills that previous research suggested would benefit from the unique capabilities of DMT compared to single-ship simulation or large-force exercises. In single-ship simulator training exercises such as responding to in-flight emergencies, an instructor introduces an emergency giving the student the opportunity to respond. Events are highly scripted and the instructor can easily evaluate good vs poor performance. In contrast, large-force exercises are much less scripted at the level of individual warfighters. Evaluators will know where and when forces will engage but will have only limited control over each participant's experience. DMT incorporates the scenario control qualities of single-ship simulator training with capabilities to enhance team and inter-team skills. The actions of computer-generated forces in RoadRunner '98 were designed to create training scenarios that would exercise specific individual, team, and inter-team skills. Among fighter pilots, these can be high-level, individual skills such as using air-to-air radar to build situation awareness or react to threats; team skills such as communication and maintaining mutual support; or inter-team skills, which require coordination among pilots and air weapons controllers or a FAC. RoadRunner '98 scenarios were, therefore, generated based on exercise objectives, technical feasibility, similarity to missions in the F-16 and F-15 RAP, and integration of mission skills that could be enhanced by experience using DMT.

Gaming area. RoadRunner '98 exercises were conducted over a synthetic Red Flag gaming area. This area was selected because it was familiar to participants and databases were available at all of the RoadRunner '98 sites. For all missions, the eastern side of the gaming area was friendly (blue) controlled territory while the western side was enemy (red) controlled. Missions began with the blue forces airborne just to the east of a landmark known as Student Gap; see Figure 7, point 1. Except for the CAS and Defensive Counterair (DCA) missions, blue forces departed from friendly airspace (pushed) at Student Gap and proceeded west crossing the Forward Edge of the Battle Area (FEBA) and attacking surface targets in enemy territory. For

the CAS mission, targets were surface vehicles near the FEBA and for DCA both F-15s and F-16s defended blue airspace against incoming red aircraft.

Red airspace was defended by SAMs and Anti-Aircraft Artillery (AAA) positioned near the FEBA. SAM sites are depicted in Figure 7 by hexagons labeled 2, 6, and 8. Enemy controlled territory was also defended by constructive Su-27 fighters plus constructive and virtual MiG-29s stationed at Tolicha and Tonopah airfields near the western edge of the gaming area. RoadRunner '98 scenarios took place within a gaming area approximately 90 by 120 NM.

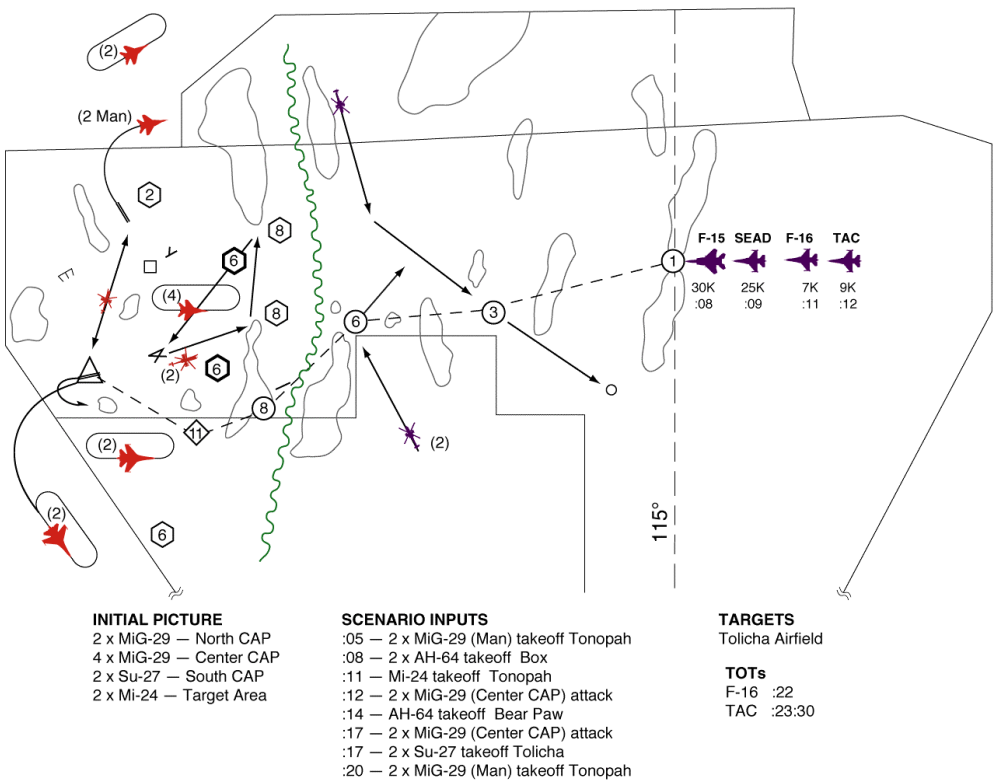


Figure 7. Map of SAT 1 mission

Unconstrained environment. In a normal, range exercise conducted at Red Flag, safety, security, and environmental considerations impose limits on where aircraft may fly, what altitudes they may select, and where they may deliver ordnance. Warfighter training in synthetic battlespace is not constrained by these limitations. RoadRunner '98 mission scenarios developed by the white cell required pilots to fly specified routes to and from the target areas. These routes were selected to insure that pilots would encounter constructive entities positioned on the ground or programmed to fly through the gaming area. If attacked, however, pilots were free to deviate from planned routes, altitudes, or airspeeds. Tactical execution in RoadRunner '98 could be based entirely on mission requirements and not limited by artificial constraints.

The virtual F-16s at AFRL/HEA had the option to select real-time kill removal (shields-down) or to disable kill-removal (shields-up). When flying with shields-down, a virtual F-16

that was hit by AAA or a missile would freeze-up and be removed from the battlespace. When flying shields-up, the out-the-window visual display flashed red for several seconds when the aircraft was hit but the pilot kept flying and was able to complete the mission. The number of times that each F-16 was killed was recorded. All missions except for Interdiction were flown shields-up. This option was selected so that pilots would be able to evaluate all aspects of training in the virtual battlespace. The F-15 cockpits did not have the capability to fly shields-up but could be regenerated quickly after being shot down.

Roles of teams and mission commander. For all RoadRunner '98 missions except CAS and DCA, the mission of the virtual F-15s was to conduct a pre-strike sweep to eliminate red air threats by pushing approximately five minutes ahead of the F-16 strike package and engaging red fighters. During CAS and DCA, the F-15s defended an assigned area against incoming red fighters.

The role of the virtual F-16s in RoadRunner '98 missions, except for DCA, was air-to-surface attack using non-precision munitions such as Mk-82, Mk-84, and CBU-87 bombs. The targets and types of enemy defenses varied across missions. In the DCA mission, the virtual F-16s defended an assigned area against incoming red fighters.

The task of the AWACS team was to provide information necessary to conduct counter-force maneuvers. This would include detecting and tracking all aircraft and identification as to whether a beyond visual range (BVR) target aircraft was friendly or hostile as defined by the rules of engagement. AWACS Weapons Directors would communicate this information to pilots using a standardized set of brevity codes to describe the number of enemy threats, their locations, heading, altitudes, airspeeds, and maneuvers. Weapons directors also provided vectors to threat and friendly aircraft as requested by pilots.

The lead F-16 pilot was the Mission Commander for all RoadRunner '98 missions except for DCA where the lead F-15 pilot was commander. The commander's task was to coordinate the actions of the different virtual teams within the constraints of the Air Tasking Order (ATO), brief the teams on the mission plan, and to lead debrief. During RoadRunner '98, the Mission Commander had no control over constructive, blue elements.

Composite Force Missions

Six composite force missions were selected for RoadRunner '98. The criteria for selection was that each mission required at least one four-ship formation of both F-15s and F-16s and that the mission was part of the current RAP tasking. For each mission, white cell intelligence officers provided teams with an ATO, special instructions (SPINS), route of flight, target, and known threats (see Appendix A). Instructors and evaluators were also provided with a chart showing red force actions that had been scripted for each mission; Figure 7 is an example of this chart. Missions were flown according to the schedule described in Table 1a. All missions began with blue forces initialized in flight east of Student Gap with the F-16s in formation behind a constructive KC-135 tanker as if they had just completed refueling. The F-15s were in an orbit nearby. The actual push from Student Gap occurred approximately ten minutes after the mission began to allow the AWACS crew to identify aircraft on their radar displays and to build situation awareness of threat activity. Missions were terminated by the exercise director when the virtual F-15s and F-16s returned to blue airspace. This required 30-45 minutes depending on the mission.

Table 1a. Schedule for RoadRunner '98 week

Mon 13 Jul	Tue 14 Jul	Wed 15 Jul	Thu 16 Jul	Fri 17 Jul
Travel, Inbrief, Questionnaires	Test 1: Surface Attack Tactics	Interdiction	Suppression of Enemy Air Defense: Conventional	Test 2: Surface Attack Tactics; Outbrief, Questionnaires
Familiarization ride	Offensive Counter Air: Air-to-Ground	Defensive Counter Air	Close Air Support	

Familiarization. On Monday afternoon pilots flew a familiarization mission. Pilots were initialized over Nellis AFB and flew around the local area using their radars and missiles to engage each other. The purpose of this exercise was to become familiar with visual appearance of other aircraft and to observe the red, flashing screens indicating that the pilot had been killed. Pilots were re-initialized over Student Gap and flew air-to-air sweeps against constructive forces with AWACS support. Participants used their respective debrief systems to replay the mission.

Surface Attack Tactics (SAT 1 and 2)—Pre-test and Post-test missions. After the familiarization ride, the first (Tuesday morning) and last (Friday morning) RoadRunner '98 missions flown were SAT sorties which are air-to-surface, tactical strike missions in a high threat environment. In SAT 1 and 2, the F-15s were tasked to provide a pre-strike sweep while the virtual F-16s were tasked to employ ordnance against a fuel pump-house and a communications facility located at Tolicha airfield indicated by a triangle on Figure 7. In addition to the virtual simulators, two flights of constructive F-16s also participated. The first was a four-ship formation of F-16 Block 50 aircraft equipped with HARMs that were to be employed against two SA-6 sites. The second constructive element was a four-ship formation of F-16 Block 30 aircraft that was also tasked to attack Tolicha airfield 1.5 minutes following the virtual aircraft. Virtual MiG-29s engaged the F-15s during their pre-strike sweep and were re-initialized to engage the F-16s during their egress. The virtual F-15s and F-16s also encountered both blue and red helicopters during their ingress. SAT missions 1 and 2 were nearly identical except for the route of flight and initial locations of red forces. SAT 1 and SAT 2 served as pre-test and post-test missions designed to be relatively high-intensity missions that would present significant challenges to participating pilots and AWACS.

Offensive Counterair: Air-to-Ground (OCA A-G). The OCA A-G mission was similar to SAT but with fewer challenging elements. Virtual F-15s and F-16s pushed from a point north of Student Gap while the constructive flights of F-16C Block 50s and Block 30s pushed from another point. Constructive Block 50s were tasked to suppress SA-6 sites with HARMs and the constructive Block 30s employed ordnance on a second airfield. The targets were larger than for the SAT mission, e.g., runway intersections, there were no helicopters in the scenario, and there

were fewer air and surface threats. However, an unbriefed SA-6 site went active while the virtual F-16s were egressing.

Table 1b. Schedule for Tue, 14 Jul 98

Time (DC) TBA	Time (OK) Tinker	Time (NM) TACCSF	Time (AZ) AFRL	Team A	Team B	Team C
1000-1030	0900-0930	0800-0830	0700-0730	Brief Test Mission		
1030-1100	0930-1000	0830-0900	0730-0800			
1100-1130	1000-1100	0900-0930	0800-0830	Fly Test 1		
1130-1200	1030-1100	0930-1000	0830-0900		Brief Test Mission	
1200-1230	1100-1130	1000-1030	0900-0930	Debrief Test Mission		
1230-1300	1130-1200	1030-1100	0930-1000		Fly Test 2	
1300-1330	1200-1230	1100-1130	1000-1030			Brief Test Mission
1330-1400	1230-1300	1130-1200	1030-1100	Lunch break	Debrief Test Mission	
1400-1430	1300-1330	1200-1230	1100-1130			Fly Test 1
1430-1500	1330-1400	1230-1300	1130-1200	Brief OCA A-G		
1500-1530	1400-1430	1300-1330	1200-1230		Lunch break	Debrief Test Mission
1530-1600	1430-1500	1330-1400	1230-1300	Fly OCA A-G		
1600-1630	1500-1530	1400-1430	1300-1330		Brief OCA A-G	
1630-1700	1530-1600	1430-1500	1330-1400	Debrief OCA A-G		Lunch break
1700-1730	1600-1630	1500-1530	1400-1430		Fly OCA A-G	
1730-1800	1630-1700	1530-1600	1430-1500			Brief OCA A-G
1800-1830	1700-1730	1600-1630	1500-1530		Debrief OCA A-G	
1830-1900	1730-1800	1630-1700	1530-1600			Fly OCA A-G
1900-1930	1800-1830	1700-1730	1600-1630			
1930-2000	1830-1900	1730-1800	1630-1700			Debrief OCA A-G
2000-2030	1900-1930	1800-1830	1700-1730			
2030-2100	1930-2000	1830-1900	1730-1800			

Interdiction. The Interdiction mission incorporated more air and surface threats than OCA A-G and was flown shields-down. The target was a storage depot. Constructive Block 50s were tasked to suppress an SA-6 site and an SA-2 site near the target. Constructive Block 30s attacked an airfield due south of the storage depot. Egress routing was identical for virtual and constructive players.

Defensive Counterair (DCA). This was the only exclusively air-to-air mission during RoadRunner '98. Virtual F-15s were tasked to defend a corridor north of a specified latitude while F-16s defended a corridor to the south. Each flight assumed a Combat Air Patrol (CAP) staying west of Student Gap but east of the FEBA to avoid red surface threats. Both flights defended blue territory from air attacks by constructive MiG-23 strikers that were escorted by virtual and constructive MiG-29s plus constructive Su-27s. The DCA mission was longer than the other RoadRunner '98 missions requiring at least 45 minutes to complete.

Suppression of Enemy Air Defenses—Conventional (SEAD-C). In the SEAD-C mission, the virtual F-16s were tasked to deliver non-precision guided munitions against a non-active SA-2 site while constructive F-16 flights attacked active SA-6 sites and two airfields. In addition to the virtual and constructive air threats seen on previous RoadRunner '98 missions, a constructive flight of MiG-23 strike aircraft flew through the area to attack blue territory. Virtual F-15s were tasked during the mission to swing from pre-strike sweep to a DCA role and engage the MiG-23s.

Close Air Support. For the CAS mission, the F-15s flew a DCA role while F-16s provided CAS for blue surface forces near the FEBA. This was a low-threat mission in that there was an SA-8 site near the target area but no air threats. F-16 attacks were directed by an A-10 pilot serving as an airborne FAC. Targets were formations of T-72 tanks.

Schedule and Daily Operations

Three teams of pilots and AWACS crews participated in RoadRunner '98 which required that each mission be conducted three times. To accomplish this and to adhere to the overall schedule listed in Table 1a, a daily schedule was adopted that overlapped briefings, missions, and debriefings; see Table 1b. At the beginning of each briefing period, the Mission Commander telephoned the other flight lead and the AWACS senior controller to review the mission plan. Each team then briefed their plan until their assigned simulator time. Although scenarios were programmed to last less than 45 minutes, each team was allotted 60 minutes of simulator time in case of technical problems. When the scenario was completed without difficulty and there was time available, the F-16 flight at AFRL/HEA went offline and conducted 4 vs X air-to-air engagements against a constructive red force. See Appendix B for descriptions of sample engagements.

Teams conducted their debriefing in two phases: local (team) and wide-area (inter-team). During local debrief, teams would replay the mission tape with the goal of understanding what happened during the mission and generating points for review by all participants. After 30 minutes, teams were to prepare a list of topics (high points and low points) and fax them to the Mission Commander. The Mission Commander then had ten minutes to prepare the inter-team debrief. Two secure speaker phones were available at AFRL/HEA. To begin the debrief, the F-16 team was to call TACCSF and Tinker to establish secure voice communications. All teams would then restart their tapes at the beginning of the mission and pause for discussion as directed

by the commander. At the conclusion of debrief, participants filled out a brief questionnaire that focused on identifying systems or procedures that reduced training value of the mission.

Personnel

The objectives of the RoadRunner '98 exercise focused on determining the effectiveness of DMT systems for training operational warfighters. Participants were therefore pilots and AWACS mission crews assigned to operational squadrons and represented a mix of experience levels.

F-16 pilots. Fifteen F-16 pilots participated in this exercise. The 522nd Fighter Squadron (FS) and 523 FS from the 27 FW, Cannon AFB NM; the Iowa Air National Guard; and the 185 and 132 FWs, each sent a team of five pilots. Squadrons were requested to send one instructor pilot, one mission commander, one 2- or 4-ship element leader, and two mission-ready wingmen. The mean number of F-16 flight hours for these pilots is shown in Figure 8a. Five of the wingmen plus one element leader had no flight experience other than F-16 and undergraduate pilot training. The other two wingmen had over 1,000 hours each in previous assignments to non-fighter aircraft. The four mission commanders and three instructors had between 700 and 1,600 hours experience in F-16s. Three of these pilots had over 1,000 hours experience in nonfighter aircraft. For further analyses, pilots were grouped into two categories, less experienced pilots (wingmen and element leaders) and more experienced (mission commanders and instructors); see Figure 8b.

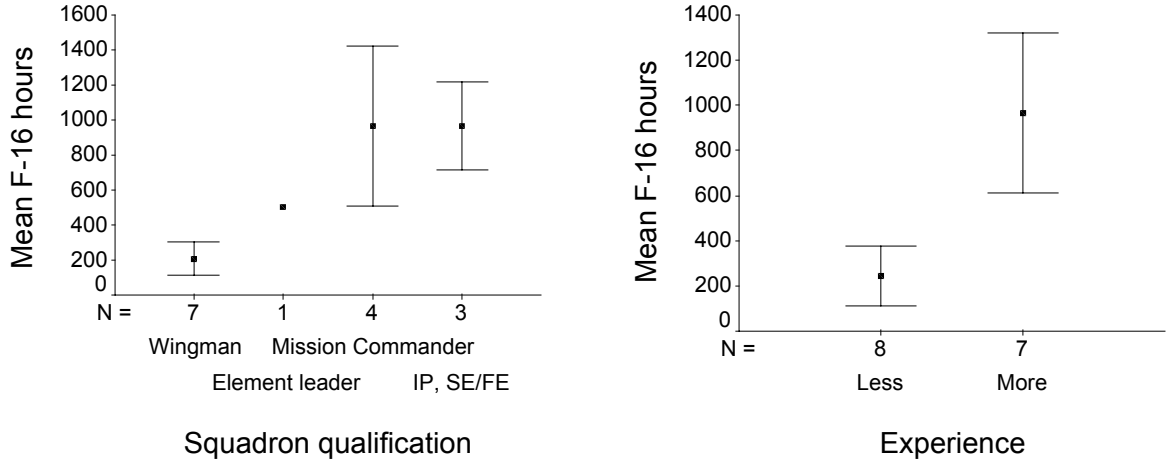


Figure 8. a) F-16 flight hours by squadron qualification

b) F-16 flight hours for more and less experienced pilots

F-15 pilots. Six F-15 pilots participated in RoadRunner '98: five from the 33 FW, Eglin AFB FL and one from the United States Air Forces in Europe who was currently assigned to a staff position. These pilots averaged over 1,000 F-15 hours experience with only one having fewer than 500 hours.

AWACS teams. Fifteen AWACS mission crewmembers from the 552 ACW, Tinker AFB OK divided into three teams participated in RoadRunner '98. Each team included one instructor, two weapons directors, and two air surveillance technicians. Mean experience level was 620 flight hours in the E-3 and 201 hours in the AWACS simulator.

Other participants. Two A-10 instructor pilots from the 355th Wing, Davis-Monthan AFB AZ, participated as airborne FACs during the CAS mission. Both of these pilots had over 1,000 hours experience in the A-10. Two pilots from the 549th Combat Training Squadron (Air Warrior), Adversary Tactics Flight, at Nellis AFB NV, participated as virtual red air threats at TACCSF; and three intelligence officers, one from each F-16 team, prepared briefing materials and briefed their pilots at AFRL/HEA.

Data Collection

Separate data collection procedures and instruments were used for pilots and AWACS teams. Data included mission performance scores, instructor or subject-matter expert evaluations, participant questionnaires, and participant comments.

Pilot data. Questionnaires. After receiving an in-brief and overview of the exercise, all pilots completed a questionnaire asking them to rate the effectiveness of their current aircraft training program with respect to several mission tasks and elements. Effectiveness of the current program was rated on a zero to four scale with the anchors:

0 = Negative training for combat; aircraft training reduces combat readiness, and

4 = Total positive training; aircraft training is equivalent to combat experience.

After the final DMT mission, pilots completed a similar questionnaire rating the effectiveness of DMT for training the same list of tasks and elements. For this questionnaire, the scale anchors were:

0 = Negative training for combat; DMT reduces combat readiness, and

4 = Total positive training; DMT is equivalent to combat experience.

Mission performance on SAT 1 and 2. Measures of mission performance were collected from the DIS log files. F-16 bomb score (distance in feet from the designated mean point of impact) was computed directly from recorded data. Red kills and blue losses to surface and air threats could not be determined directly or automatically from data. When flying shields-up, a virtual F-16 would not disappear from the battlespace when killed by a red threat. Therefore, a constructive threat would continue to track the F-16 and kill it over and over until the exercise director could order it to disengage. This problem and other difficulties with constructive forces required interpretation by a subject-matter expert. For scoring purposes, only the first kill was counted.

Interviews and critiques. Pilot critiques were collected after each mission and on the training effectiveness questionnaires. F-16 pilots were also interviewed after three of four DMT missions regarding system successes and shortfalls and their judgments regarding best use of DMT.

F-16 Instructor Pilot evaluation. F-16 team process data were collected for this effort using two different approaches that have been successfully used in previous training research efforts (see, Dwyer, Oser, Salas, & Fowlkes, 1999). While both of the approaches were designed to assess performance and provide feedback to teams, the nature of the type of data obtained differ.

Table 2. Dimensions and key factors for Teamwork Oriented Measurement (TOM) scales

DIMENSIONS (Higher order skills)
COMMUNICATION – the exchange of information between two or more team members. Descriptors – (1) Information Exchange – involves the clear, concise, and accurate exchange of information between elements of the team, (2) Information Clarification – involves the detection of inaccurate or incomplete information and taking corrective action, (3) Information Cadence – involves the timing, rhythm, and flow of information, and (4) Information Format – involves the terminology and order of the information SITUATION AWARENESS – the exchange of information used to develop and maintain an accurate perception of the operating environment. Descriptors – (1) Maintaining an Overall Mission View – involves interactions involving mission goals and how situational factors are affecting the mission goals, (2) Monitoring Mission Deviations–involves interactions related to detection and communication of changes in operational environments that could affect the mission plan, (3) Monitoring Mission Progress – involves interactions related to the current location and status of mission assets, (4) Understanding Current Mission State – involves interactions that demonstrates the team's shared and common understanding of the mission status, and (5) Assessing Future Mission States – involves interactions related to potential modification of mission plan ADAPTABILITY/FLEXIBILITY – exchange of information related to modification of plans Descriptors – (1) Maintaining the Pre-Briefed Plan – involves interactions demonstrating that the team will not modify its existing plan, (2) Changing to a Pre-Briefed Alternate Plan – involves interactions demonstrating that the team will be modifying its current plan to a previously briefed alternate plan, and (3) Changing to a Non-Briefed Plan – involves interactions demonstrating the team will modify its current plan to a plan that was not previously briefed CREW COORDINATION – the exchange of information related to team synchronization. Descriptors – (1) Providing Information in Advance – involves interactions related to team members anticipating team members' needs for information and providing the information prior to its request, (2) Providing Back-Up When Required – involves interactions related to team members recognizing need for assistance and providing such assistance, and (3) Maintaining Contracts – involves interactions related to team member implicit interactions agreed upon during the mission brief

The first approach, the Teamwork Observation Measure (TOM), focuses on the identification of strengths and weaknesses at the higher order skill, or dimensional level. Four dimensions (or higher order skills) were considered critical for effective performance in this environment: Communication, Situation Awareness, Adaptability/Flexibility, and Coordination. Each of the four dimensions was defined and then decomposed into key factors. "Communication," for example, was defined as "the exchange of information between two or more team members" and was decomposed into four key factors: information exchange—clear, concise, and accurate exchange of information between elements of the team; information clarification—detection of inaccurate or incomplete information and taking corrective action; information cadence—timing, rhythm, and flow of information; and, information format—terminology and order of the information. The definitions and key factors associated with each of the dimensions are listed in Table 2. For each of the dimensions, evaluators were to provide a rating for each mission phase using a 5-point scale with the anchors: 1—Dangerous, 2—Below Average, 3—Nominal, 4—Above Average, and 5—Extraordinary. The observers were also asked to provide an overall mission rating for each of the dimensions and an overall mission grade using the same scale. A sample TOM gradesheet used in RoadRunner '98 is presented in Table 3a.

Table 3a. Gradesheet used to assess TOM dimensions for each mission phase

Phase/Dimension	Communication	Situation Awareness	Adaptability/ Flexibility	Crew Coordination	Notes
Brief					
Prior to Push					
Ingress					
Combat Air Patrol Formation					
Intercept Engagement					
Ground Target Attack					
Egress					
Debrief					
Overall Mission					

Table 3b. Sample gradesheet used to assess team performance using TARGET

INGRESS	**4 Middle ATES, 2 South ATES, 2 Red Helos, 1 Blue Helo, SEAD, TAC, F-15, F-16, 2 Blue Helos, 2 Manned Red –1, 2 South ATES**	**Grade**	**Notes**
(East of FEBA)	AWACS provides updated picture		
	Acknowledge/respond to AWACS as appropriate (e.g., in v. out of range)		
	Fighter provides updated contact report (terminology and timing appropriate)		
	AWACS helps maintain picture with acceptable timing and cadence		
	Discuss Implications for Ingress/Egress Routes		
	Push Calls?		
(West of FEBA)	AWACS provides updated picture		
	Acknowledge/respond to AWACS as appropriate (e.g., in v. out of range)		
	Fighter provides updated contact report (terminology and timing appropriate)		
	AWACS helps maintain picture with acceptable timing and cadence		
	Discuss Implications for Ingress/Egress Routes		
Ground-to-Air Systems	SA-2, SA-6, SA-8		
	Detection		
	Avoidance		
	Assess Implications		
	4 Middle ATES, 2 South ATES, 2 Red Helos, 1 Blue Helo, SEAD, TAC, F-15, F-16, 2 Blue Helos, 2 Manned Red –1, 2 South ATES		
If Air Intercepts Performed During Ingress	Fighter provides descriptive calls with acceptable timing and cadence		
	Radar Search, Detection, Lock-on		
	Intercept Execution		
	Sort Call		
	Targeting plan communicated		
	Tactical considerations discussed		
	Weapons employment communicated		
	Directive calls at merge timely and appropriate (e.g., cranking, notching, intentions (engages, blowthrough), joker, egressing)		
	Leaker calls (positive or possible)		
	Identification of Unknowns		

The second approach is referred to as Targeted Acceptable Responses to Generated Event or Tasks (TARGET). The TARGET approach looks at proficiency with respect to scenario events. Events can be associated with a specific mission phase as a course of normal operations (e.g., ingress, ground attack, egress) or associated with situations that are incorporated into a scenario to present anomalous, nonroutine, or unplanned situations (e.g., loss of communications, inaccurate intelligence). The TARGET approach uses behaviorally focused scales for recording observations of team behaviors for given events using the same 1 to 5 scale as TOM. Events are arranged on the gradesheet in the approximate order in which they are expected to occur in a scenario. A sample TARGET gradesheet used in RoadRunner '98 is presented on Table 3b.

AWACS data. Prior to the RoadRunner exercise, 38 expert AWACS weapons directors were interviewed. These subject-matter experts identified four teamwork functions that are essential to AWACS team performance: (a) mission planning, (b) communication content/timing, (c) adherence to support situation awareness, and (d) supporting behavior.

Mission planning: formulation of contracts. Mission planning affects AWACS teamwork by establishing roles and responsibilities, and through contingency planning. As discussed by Fahey, Rowe, Dunlap and DeBoom (in press) and MacMillan et al. (1998), AWACS weapons directors explicate roles, responsibilities, and strategies to manage team member interdependencies through establishment of agreements that are referred to as contracts. These contracts are made among AWACS team members (internal contracts), and to the external team (i.e., pilots of friendly assets).

Communication: adherence to protocol. AWACS weapons director tasks are predominately verbal information exchange. Communications are heavily standardized in terms of content (jargon) and process. This aspect of communication effectiveness refers to the degree to which individuals follow guidelines for communication exchange. In addition to proper jargon and syntax, communications must be clear, concise, and correct.

Communication to support situation awareness. Communications may be clear, concise, correct, and delivered according to proper protocol, and still be superfluous. Maintenance of situation awareness also requires that pertinent information be exchanged to the right person, at the right time. In such a communication-rich environment, too much communication can impede performance, when unnecessary information interferes with other, higher priority communication. Indeed, part of the proper timing of AWACS communications to pilots involves knowledge of when to keep quiet.

Supporting behavior. AWACS team members support each other primarily through updates and reminders of salient information. At the same time, they can also transfer resources (responsibilities) and confer on decisions/actions.

A rating instrument was tailored to capture these dimensions across three phases of performance: (a) premission briefing, (b) mission performance, and (c) mission debriefing. Ratings were based on a 4-point rating scale. Standards for performance ratings in RoadRunner '98 were the same as used in AWACS training:

0 = No Ability or Knowledge. Task failure

1 = Lacks Proficiency (Coordination, communication, cohesion). Uncorrected errors. Degraded mission outcome or endangered friendly forces.

2 = Limited Proficiency. Recognizes and corrects errors with team recovery. Mission Degraded.

3 = Proficient. No mission impacting errors. Team reacts correctly in current situations.

4 = Highly Proficient. Prevents errors. Team anticipates future situations. Plans ahead.

NA = Not Applicable

NO = Not Observed

NP = Not Performed

Procedures

Systems design, scenario development, and network testing occurred over several months prior to the exercise. Given that RoadRunner '98 incorporated four active sites (AFRL, TACCSF, AFIWC, and AWACS), four types of virtual simulators (F-15s, F-16s, MiGs, and AWACS) and several sources of constructive entities, much of the development effort was devoted to testing the many interactions among entities. For any given pair of fighter aircraft, interactions include: visual appearance, radar detection and tracking, operation of each cockpit's RWR, missile lock-on and flyout, and effects of countermeasures on missiles.

The RoadRunner '98 exercise began on Monday, 13 Jul 98, with in-briefings for participants at each location, administration of questionnaires, and a familiarization flight. The goal of the familiarization flight was to provide participants with experience in the simulators and using the debrief systems.

On Tuesday through Thursday teams flew two missions per day; a representative daily schedule is shown on Table 1b. Each mission began with a one-hour brief at each location. Participants were to be in their cockpits by the beginning of the mission period. Scenarios were designed to last between 35 and 45 minutes with extra time allotted in the schedule for slips and restarts. After completion of the mission, 90 minutes was allocated for debrief. After debrief, participants completed a feedback form that included items on systems difficulties and perceived training effectiveness.

The RoadRunner '98 exercise concluded on Friday, 18 Jul 98, with one mission. After debriefing this mission, teams completed a questionnaire on their assessment of DMT training effectiveness.

RESULTS

All RoadRunner '98 missions were completed as scheduled without aborts or significant delays although brief delays of up to ten minutes were not uncommon. On two occasions, one of the F-16 cockpits at AFRL/HEA failed and was inserted into the mission after rebooting the simulator. On two other occasions, one cockpit had a problem that could not be corrected and the remaining F-16s continued as a three-ship formation. Communication bandwidth among RoadRunner '98 sites was not a limiting factor. For the DCA mission, which had the highest number of entities emitting data packets, mean network traffic was 315 kilobits per second with a peak of 803 kilobits per second which is slightly over one-half the capacity of a T-1 line. Overall, the RoadRunner '98 exercise was successfully completed as planned. The following results relate to mission performance within the exercise, rated training effectiveness of DMT, and areas for improvement in DMT systems.

Mission Performance and Instructor Evaluations

The first and last missions in RoadRunner '98 were SAT scenarios (see Appendix A, SAT 1 and SAT 2). Two teams flew SAT 1 on Tuesday and SAT 2 on Friday while the other team flew the scenarios in reverse order. Data were collected for the virtual F-16s on bomb score (miss distance), red air (MiG) kills, and losses to air and surface threats. Mean bomb score for the first mission was 425 feet and 296 feet for the last mission. Since the test missions were flown shields-up, virtual F-16s could be killed more than once. On the first mission, the three teams lost a total of 15 aircraft to surface threats, 13 to airborne threats, and killed 4 MiGs. On the last mission, virtual F-16 teams lost 9 aircraft to surface threats, 6 to airborne, and killed no MiGs. (Pilot reactions to constructive forces are also described in Cicero, 1998.)

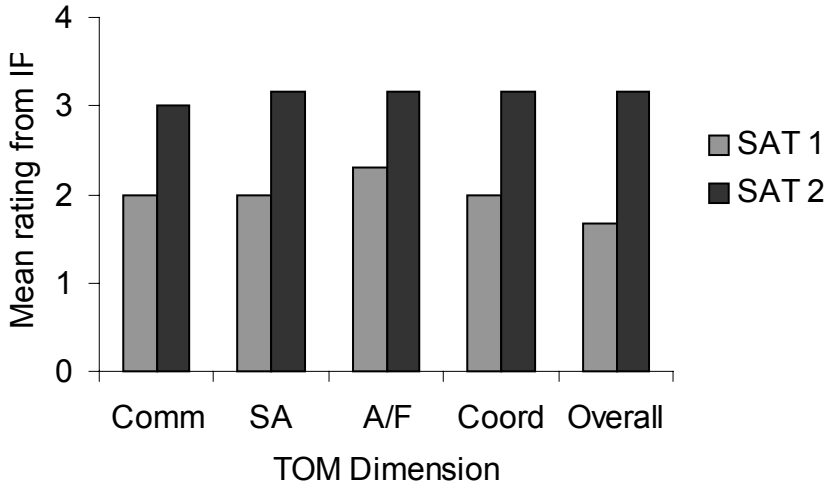


Figure 9. Mean mission performance ratings

A rating of overall mission performance on a scale of 1 to 5 was part of the TOM rating forms that were completed by each team's instructor pilot. Mean ratings for the first and last SAT missions are depicted in Figure 9. The mean rating assigned to overall mission performance for the three teams increased from 1.7 to 3.2 between the first and last missions. In addition to a rating of overall mission performance, the squadron instructor pilots rated each

team on Communication, Situation Awareness, Adaptability/Flexibility, and Crew Coordination (see Figure 9). Ratings for each of these variables for all teams increased from approximately 2 (below average) to 3 (nominal performance) except for Adaptability/Flexibility which was constant at 3 for two teams and increased from 2 to 3.5 for only one team.

Mean ratings for overall mission performance and the four higher order skills demonstrated by team A for the two SAT missions averaged across all mission phases are depicted in Figure 10a. The rating assigned to overall mission performance for team A increased from 1 (dangerous) during SAT 1 to 3 (nominal performance) during SAT 2. Mean ratings for each of the higher order skills also increased from SAT 1 to SAT 2. In an effort to further examine the performance of team A, performance by mission phase was examined. Figure 10b depicts the average ratings across the four higher order skills by mission phase. Performance during *brief*, *ground attack*, *egress*, and *debrief* improved from SAT 1 to SAT 2. In comparison, performance *prior to push* and during *ingress* did not change. Further analyses were conducted to determine the extent to which performance for each of the higher order skills changed by phase from SAT 1 to SAT 2.

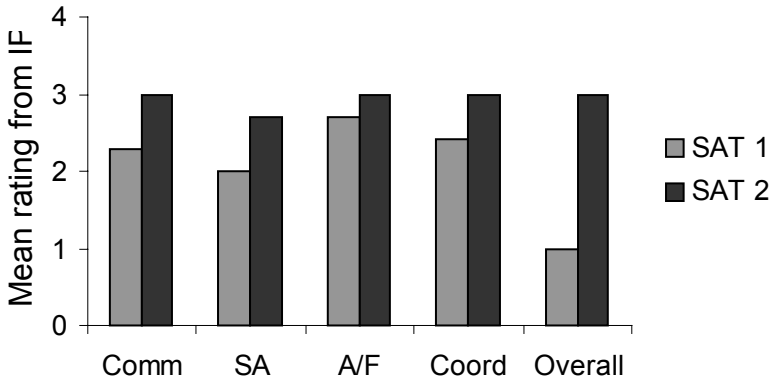
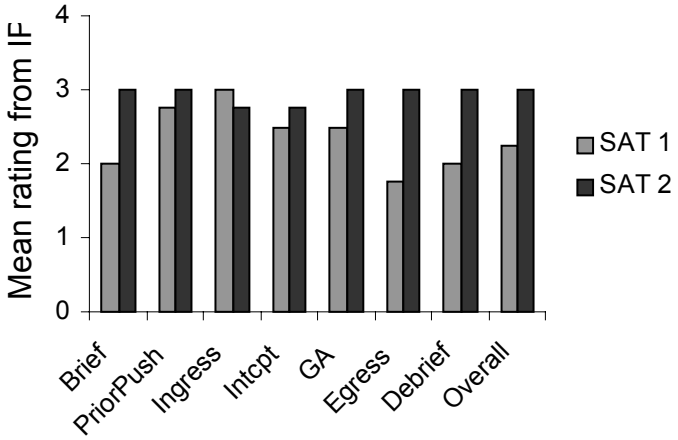


Figure 10. a) Mission performance ratings for team A



b) Mission performance ratings for team A by individual mission phases

Figure 11 shows the instructor ratings for team A for each of the higher order skills by phase of flight. Comparing performance in team A from SAT 1 to SAT 2: (a) ratings for Communication increase for *brief*, *ground attack*, *egress*, and *debrief* from below average rating to nominal, whereas ratings for *prior to push* and *ingress* did not change and were nominal; (b) ratings for Situation Awareness increased across all phases except for the *ingress* from below average or dangerous to nominal, whereas the rating for *ingress* decreased from nominal to below average; (c) ratings for Adaptability/Flexibility increased during *brief*, *egress*, and *debrief* from below average to nominal, remained at a nominal level for *prior to push* and *ingress*, and decreased from above average to nominal in *ground attack*; and (d) ratings for Coordination increased for *brief*, *ground attack*, *egress*, and *debrief* from below average to nominal, whereas ratings for *prior to push* and *ingress* did not change and were nominal.

While many of the higher order skills improved from SAT 1 to SAT 2, two decreases in ratings were observed – Situation Awareness during *ingress* and Adaptability/Flexibility during *ground attack*. The previously discussed less than nominal performance observed in *ingress* may have been the result of below average performance associated with Situation Awareness as compared to the other higher order skills which were observed to be nominal.

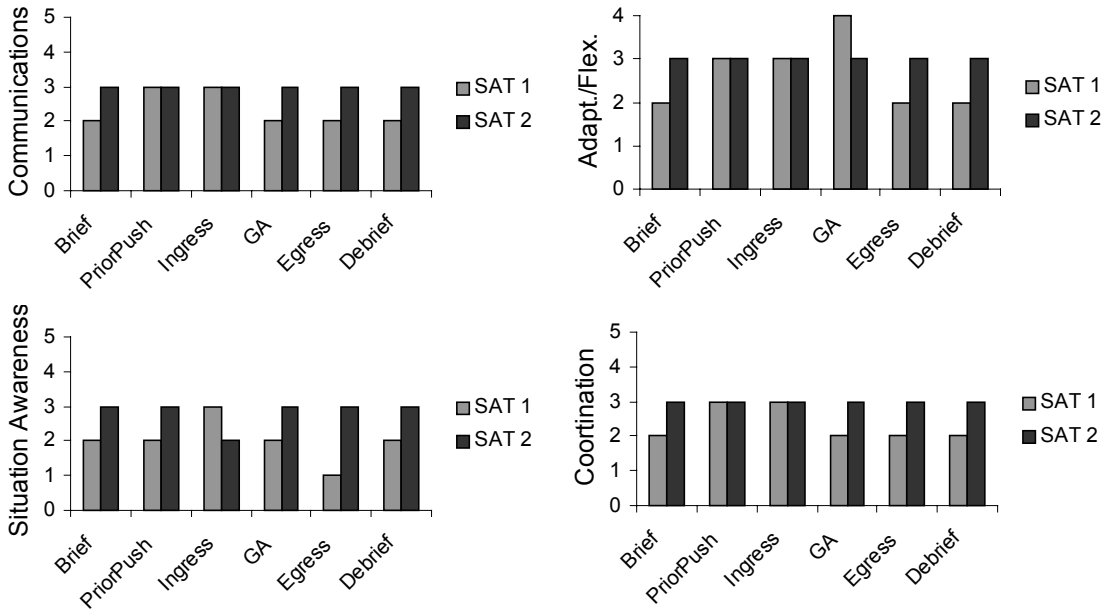


Figure 11. Skill ratings for team A for individual mission phases

To further understand the manner in which the performance of Team A changed as a function of the team's experience in DMT, the TARGETs data were examined at the task level. Behaviors were identified that either increased or decreased by one or more points from SAT 1 and SAT 2. Table 4 shows that 20 behaviors improved from SAT 1 to SAT 2 whereas only one behavior decreased from SAT 1 to SAT 2.

Table 4. Changes in TARGET behaviors for Team A

Phase	Performance Increase from SAT 1 to SAT 2	Performance Decrease from SAT 1 to SAT 2
Brief	- Review contingencies for Rendezvous - Mission allowable risk - Commit Criteria	
Prior to Push	- AWACS helps develop and maintain picture with acceptable timing and cadence	
Ingress	- AWACS provides updated picture - Fighter provides updated contact report with appropriate terminology and timing - AWACS helps maintain picture with acceptable timing and cadence - Detection of G/A Systems - Avoidance of G/A Systems - Assess implications of G/A systems	- Push Calls
Ground Attack	- Detection of G/A Systems - Avoidance of G/A Systems - Assess implications of G/A systems	
Egress	- Detection of G/A Systems - Avoidance of G/A Systems - Assess implications of G/A systems	
Debrief	- Communication - Situation Awareness - Adaptability/Flexibility - Coordination	

Mean ratings for overall mission performance and the four higher order skills demonstrated by team B for the two SAT missions averaged across mission phases are depicted in Figure 12a. The rating assigned to overall mission performance for team B during SAT 1 increased from 2 (below average) to 3 (nominal performance) during SAT 2. Mean ratings for all of the higher order skills also increased from SAT 1 to SAT 2. Figure 12b depicts the average ratings across the four higher order skills by mission phase. Performance ratings for all phases improved from SAT 1 to SAT 2 except *ground attack* which decreased. In SAT 1, performance for all mission phases was rated at or below average. In comparison, performance in SAT 2 was rated above average for *prior to push*, *egress*, and *debrief*, nominal for *briefing* and *ingress*, and slightly below average for *ground attack*. Additional analyses were performed separately for each of the higher order skills by phase for SAT 1 and SAT 2. Figure 13 shows the ratings provided by the instructor pilot for team B for each of the higher order skills by phase of flight. Comparing performance in SAT 1 to SAT 2: (a) ratings for Communication increased across all phases except for *ground attack* from nominal or below average to nominal or above average, in comparison ratings for *ground attack* decreased from nominal to below average; (b) ratings for Situation Awareness increased for *prior to push*, *ingress*, *egress*, and *debrief* from nominal or

below average to nominal or above average, ratings remained nominal for *brief*, and ratings for *ground attack* decreased from nominal to below average; (c) ratings for Adaptability/Flexibility increased for *brief*, *prior to push*, *ingress*, and *egress* from nominal or below average to nominal or above average, ratings for *debrief* remained nominal, and ratings for *ground attack* decreased from nominal to below average; and (d) ratings of Coordination for *prior to push*, *ingress*, and *egress* increased from nominal or below average to nominal or above average, and ratings for *brief* and *ground attack* remained nominal. While many of the higher order skills improve or remain stable from SAT 1 to SAT 2, ratings in the *ground attack* for Communications, Situation Awareness, and Adaptability decreased for team B. The previously identified less than nominal performance observed in *ground attack* may have resulted from below average performance associated with these higher order skills as compared to Coordination.

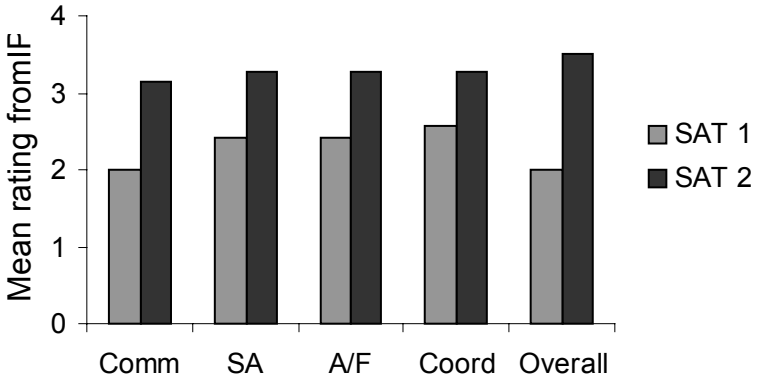
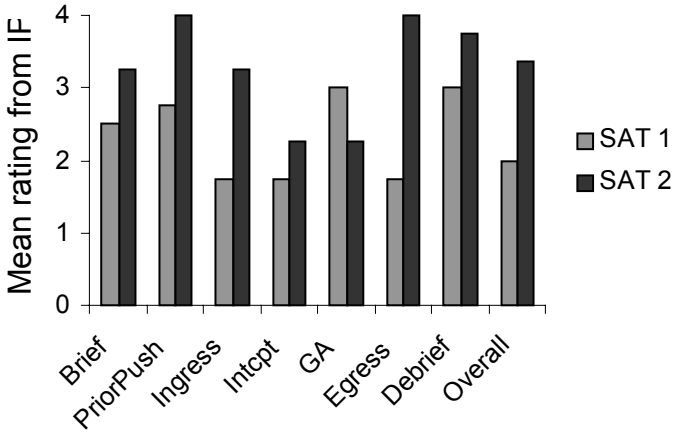


Figure 12. a) Mission performance ratings for Team B



b) Mission performance ratings for Team B by individual mission phases

The TARGETS data were examined to identify specific task-related behaviors demonstrated in both SAT 1 and SAT 2 that increased or decreased by one or more points. Table 5 shows that ratings for 43 behaviors improved from SAT 1 to SAT 2 whereas ratings for only three behaviors decreased from SAT 1 to SAT 2. All other behaviors either did not change or were not demonstrated in both sessions. Almost 50% of the behaviors that team B improved from SAT 1 to SAT 2 were associated with the *brief* phase of the mission.

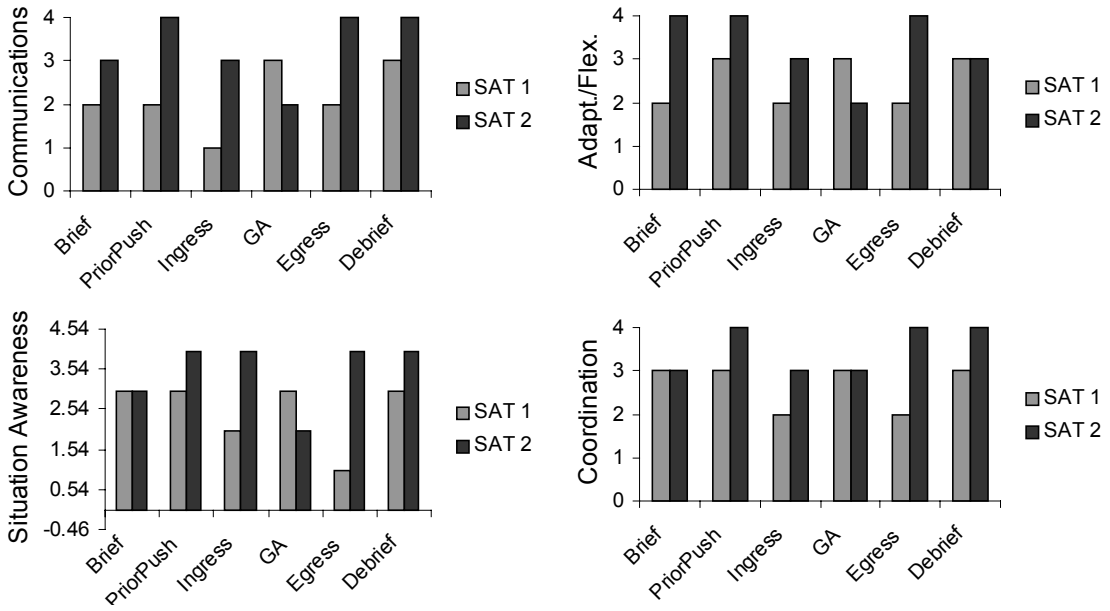


Figure 13. Skill ratings for Team B for individual mission phases

Table 5. Changes in TARGET behaviors for Team B

Phase	Performance Increase from SAT 1 to SAT 2	Performance Decrease from SAT 1 to SAT 2
Brief	- Review of tasking, mission, intelligence brief - Review ROE - Review route, entry point, target area, egress - Review boundaries, FEBA - Review ordnance loadout - Review rendezvous procedures - Review contingencies for rendezvous - Preferred calls - Cadence/discipline - Time line - TOT - Speed/altitude - Mission allowable risk - Flow - PID engagement criteria - Blue on blue deconfliction - Commit Criteria - Review of roles and responsibilities of elements - Review of procedures for handling threats - Egress speed/altitude - Egress deconfliction plan, and - Egress Communication plan	- Joker and Bugout Calls

Prior to Push	- Perform fighter to AWACS brief - AWACS to fighter brief - Alpha check - *AWACS provides initial and updated picture* - AWACS helps develop and maintain picture with acceptable timing and cadence	- Discuss implications for ingress/egress routes
Ingress	- AWACS helps to maintain picture with acceptable timing and cadence - Discuss implications for ingress/egress routes - Push calls - Detection of G/A Systems - Avoidance of G/A Systems - Fighter provides descriptive calls with acceptable timing and cadence - Radar search, detection, lock on	
Attack	- Detection of G/A Systems - Avoidance of G/A Systems	- Positive Identification of Target
Egress	- Detection of G/A Systems - Avoidance of G/A Systems - Assess implications of G/A systems	
Debrief	- Communication - Situation Awareness - Adaptability/Flexibility - Coordination	

Mean ratings for mission performance and higher order skills demonstrated during the two SAT missions by team C are depicted in Figure 14a. The rating assigned to overall mission performance for team C during SAT 1 increased from 2 (below average) to 3 (nominal performance) during SAT 2. Mean ratings for all four of the higher order skills also increased from SAT 1 to SAT 2. Ratings of team C's performance on the higher order skills by mission phase are shown on Figure 14b. Performance for *ingress*, *ground attack*, and *egress* improved from SAT 1 to SAT 2, whereas ratings for *brief*, *prior to push*, and *debrief* did not change. During SAT 1, performance was rated nominal for *brief*, *prior to push*, and *debrief*, however ratings were below average for *ingress*, *ground attack*, and *egress*. In comparison, during SAT 2, performance was nominal for all phases.

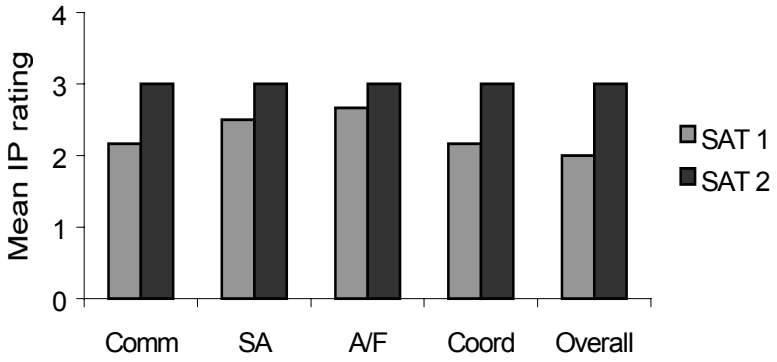
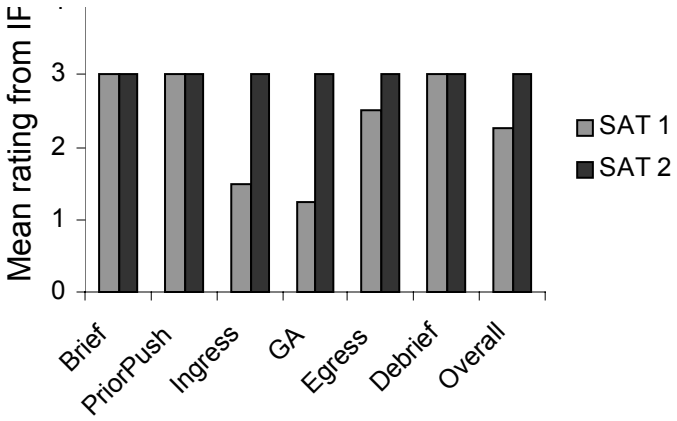


Figure 14. a) Mission performance ratings for Team C



b) Mission performance ratings for Team C by individual mission phases

Figure 15 shows instructor ratings for team C for each of the higher order skills by phase of flight. Comparing performance in SAT 1 to SAT 2: (a) ratings for Communication increase for *ingress*, *ground attack*, and *egress* from dangerous or below average to nominal, whereas ratings for *brief*, *prior to push*, and *debrief* remained nominal; (b) ratings for Situation Awareness increased for *ingress* and *ground attack* from dangerous or below average to nominal while, ratings for *brief*, *prior to push*, egress, and *debrief* remained nominal; (c) ratings for Adaptability/Flexibility increased for *ingress* and *ground attack* from below average to nominal, whereas *brief*, *prior to push*, *egress*, and *debrief* remained nominal; and (d) ratings for Coordination increased for *ingress*, *ground atta*ck, and *egress* from dangerous or below average to nominal, whereas ratings for *briefing, prior push*, and *debrief* remained nominal. All of the ratings for the higher order skills increased or remained stable from SAT 1 to SAT 2 and none of the ratings for team C decreased.

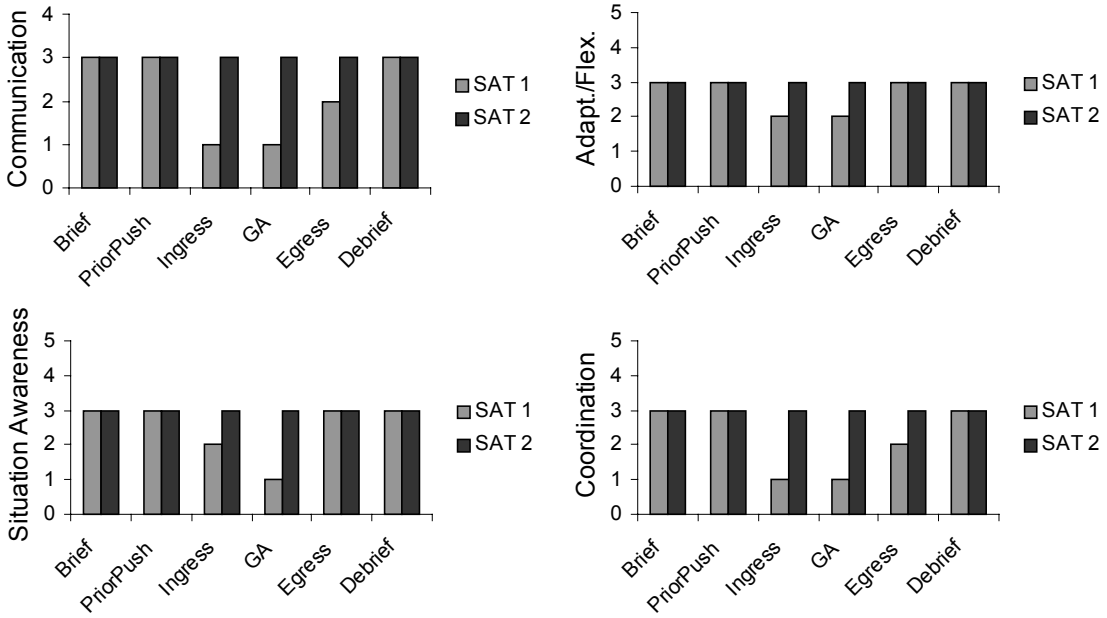


Figure 15. Skill ratings for Team C for individual mission phases

Table 6 shows that 15 TARGET behaviors were improved from SAT 1 to SAT 2 whereas three behaviors decreased from SAT 1 to SAT 2.

Table 6. Changes in TARGET behaviors for Team C

Phase	Performance Increase from SAT 1 to SAT 2	Performance Decrease from SAT 1 to SAT 2
Brief		- Review Rules of Engagement
Prior to Push	- AWACS provides initial and updated picture	
Ingress	- AWACS provides update picture - Acknowledge and respond to AWACS as appropriate - AWACS helps maintain picture with acceptable timing and cadence - Fighter provides updated contact report - Detection - Tactical considerations discussed	- Leaker calls (positive or possible)
Attack	- Delivery parameters - Request Re-Attack, if necessary - Detection of G/A Systems - Avoidance of G/A Systems - Assess implications of G/A systems	- Positive Identification of Target
Egress		
Debrief	- Communication - Situation Awareness - Coordination	

The behavioral changes obtained on the TARGETs instrument were examined to determine the number of teams demonstrating positive or negative change of one or more points for a given behavior in each phase. Table 7 lists the behaviors by mission phase that improved in two or three teams from SAT 1 to SAT 2. Seven behaviors improved across all three teams across three different mission phases. In comparison, only one behavior decreased in 2 of the 3 teams (i.e., positive identification of target during ground attack phase) and none of the behaviors were observed to decrease for all three of teams.

Table 7. Summary of changes in TARGET behaviors

Phase	Improvements in 3 of 3 teams	Improvements in 2 of 3 teams
Brief		Review contingencies for rendezvous Mission allowable risk Commit Criteria
Prior to Push		AWACS provides initial and updated picture AWACS helps develop and maintain picture with acceptable timing and cadence

Table 7. Cont.

Ingress	AWACS helps maintain picture with acceptable timing and cadence Detection of G/A systems	AWACS provides updated picture Avoidance of G/A systems Fighter provides updated contact report
Ground Attack	Detection of G/A systems Avoidance of G/A systems	Assess implications of G/A systems
Egress		Detection of G/A systems Avoidance of G/A systems Assess implications of G/A systems
Debrief	Communication Situation Awareness Coordination	Adaptability/Flexibility

Pilot Aircraft and DMT Evaluations

Pilots rated the effectiveness of their current aircraft training program for a number of mission tasks and elements at the beginning of RoadRunner '98 and repeated this questionnaire for DMT training at the end of the week.

F-15 results. F-15 pilots in RoadRunner '98 rated their current aircraft training program as most effective for improving skills in Beyond Visual Range Employment, Radar Lookout, and Radar Sorting and Employment. Aircraft training was rated as least effective for Tactical Electronic Warfare System Employment and for Reaction to AAA (Figure 16a). DMT was rated as highly effective for training: Radar Sorting and Employment, Electronic Identification, Intraflight Communication, and Engagements Against Multiple (≥ 4) Bogeys. DMT was rated as ineffective for training Gun Employment, Visual Identification, Basic Fighter Maneuvers, and Operating in a Communications Jamming Environment (Figure 16b).

The difference between the mean ratings for aircraft training and DMT was computed for each mission task or element and plotted on Figure 17. Negative values on this figure indicate that training in the aircraft was rated as more effective than DMT for a given task or element. Aircraft training was rated as much more effective than DMT for most of the rated tasks including Tactical Formation, Visual Lookout, Mutual Support, and All-Aspect Defense. Positive values indicate that ratings of training effectiveness for DMT were higher than ratings assigned to aircraft training. Only Engagements Against Multiple Bogeys, Intraflight Communications, and Reaction to AAA were assigned higher effectiveness ratings for DMT than for aircraft training.

F-16 results. F-16 pilots rated their current aircraft training programs as most effective for Tactical Formation, Tactics and Mission Planing, Debriefing, Radar Targeting and Sorting, and Visual Missile Employment (Figure 18a). Aircraft training was rated as least effective for Engagements Against Multiple Bogeys, Intercepts using Electronic Countermeasures, Reaction to AAA, and Employment of Chaff and Flares. DMT was rated as most effective for Radar Targeting and Sorting, Engagements Against Multiple Bogeys, and Radar Lookout / Mechanics and least effective for Visual Lookout, Visual Identification, Basic Fighter Maneuvers, and Tactical Formation (Figure 18b).

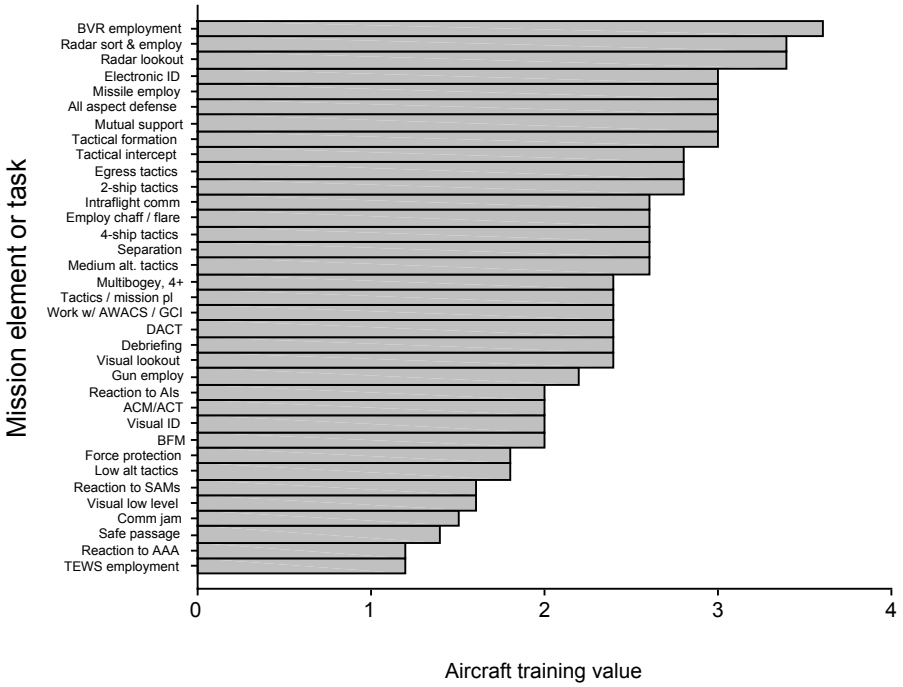
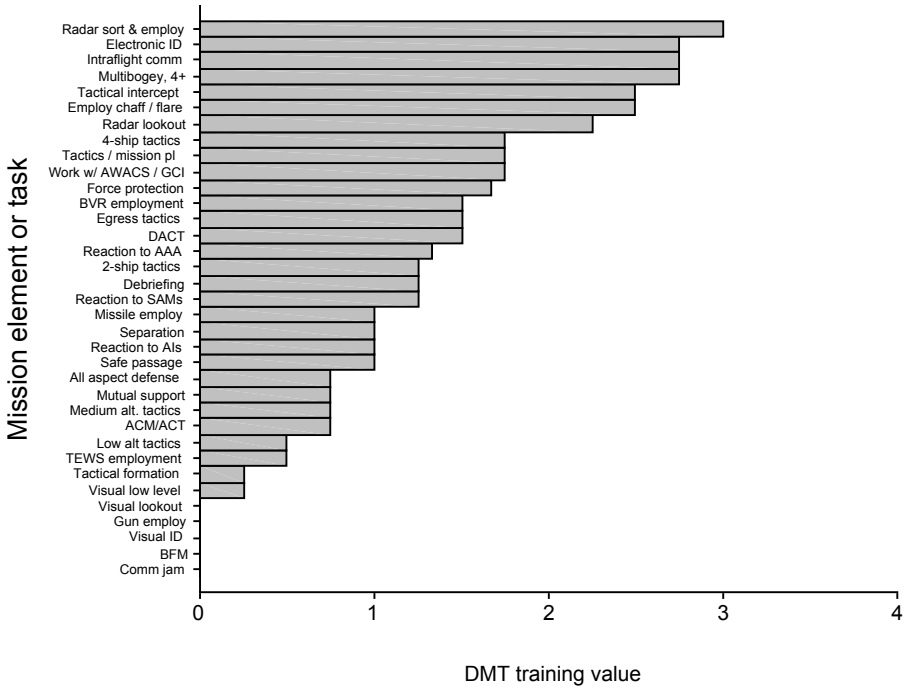


Figure 16. a) F-15 pilot ratings for aircraft training effectiveness



b) F-15 pilot ratings for DMT effectiveness

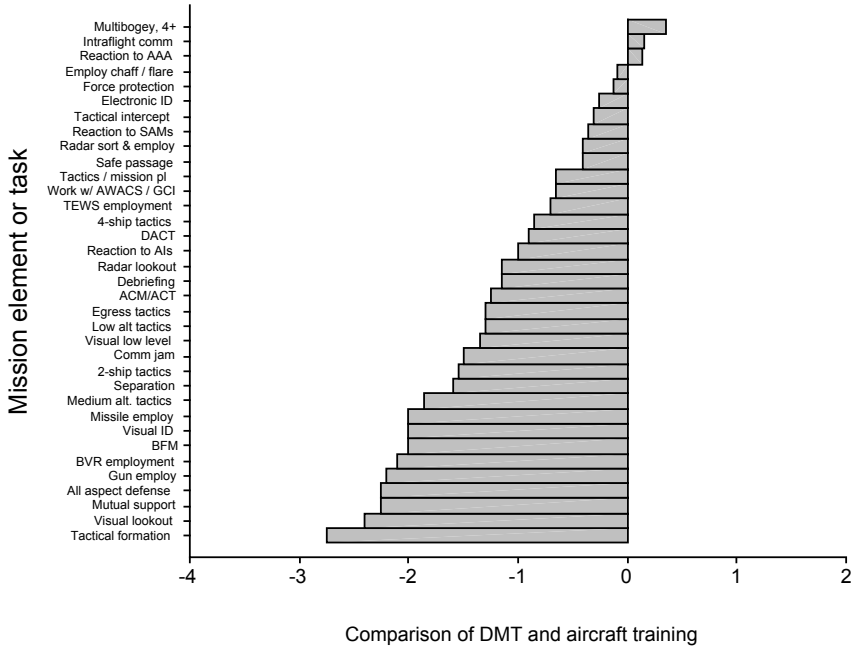


Figure 17. Differences between F-15 pilot ratings for aircraft training and DMT effectiveness

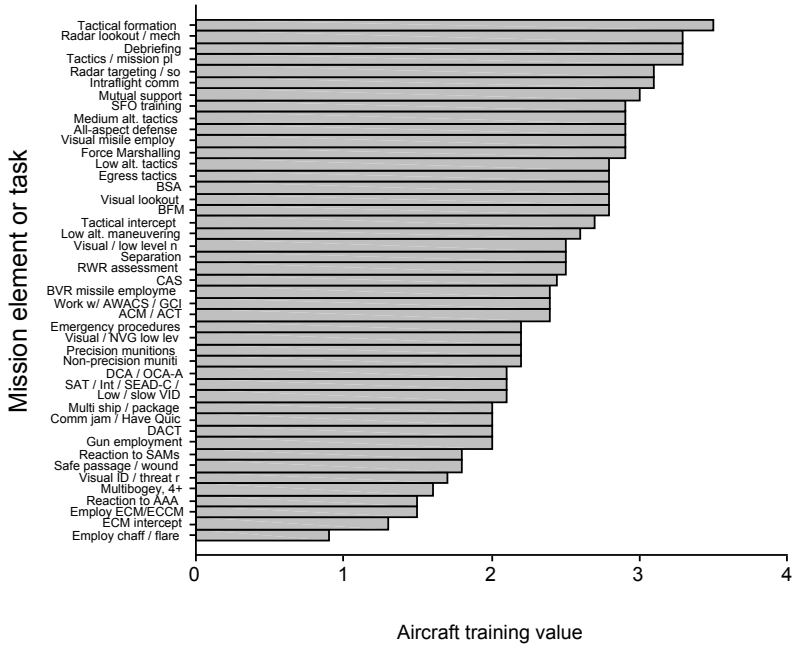


Figure 18. a) F-16 pilot ratings for aircraft training effectiveness

Comparison of the ratings assigned for each task or element shows that aircraft training was rated as more effective than DMT for several tasks including Basic Surface Attack, Mutual Support, Visual Lookout, and Tactical Formation (Figure 19). Ratings of training effectiveness assigned to DMT were higher that ratings for aircraft training for Engagements Against Multiple Bogeys, Employment of Chaff and Flares, Reaction to AAA, Multiship Tactics, and Reaction to SAMs. F-16 pilots qualified as wingmen and element leads assigned higher ratings for DMT

than aircraft training on Work with AWACS, Radar Targeting and Sorting, and Radar Mechanics. Instructor Pilots and Mission Commanders assigned higher ratings to DMT for All-aspect defense, and Multiship Package Employment.

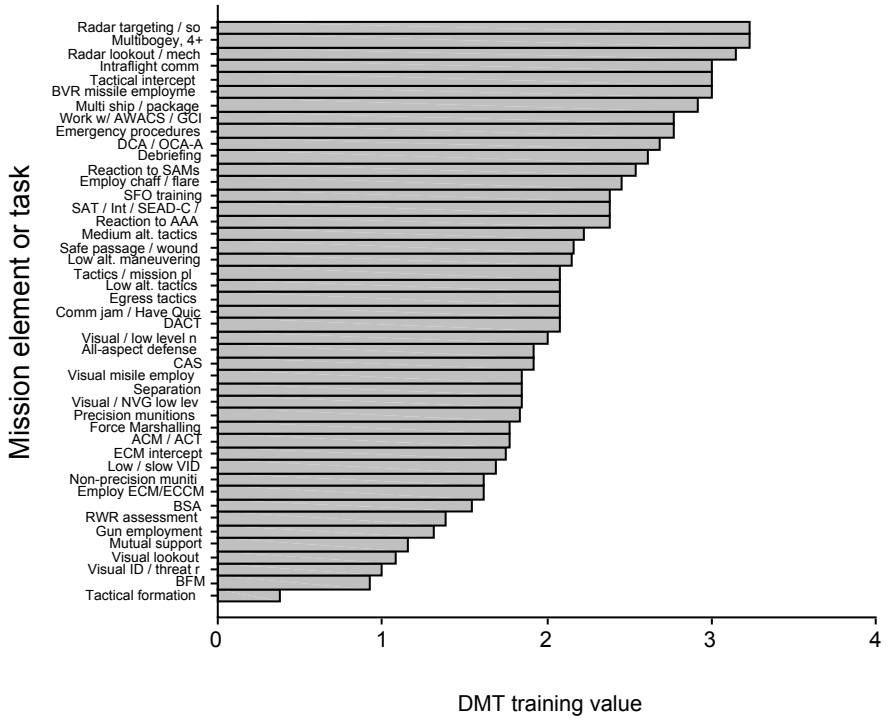


Figure 18. b) F-16 pilot ratings for DMT effectiveness

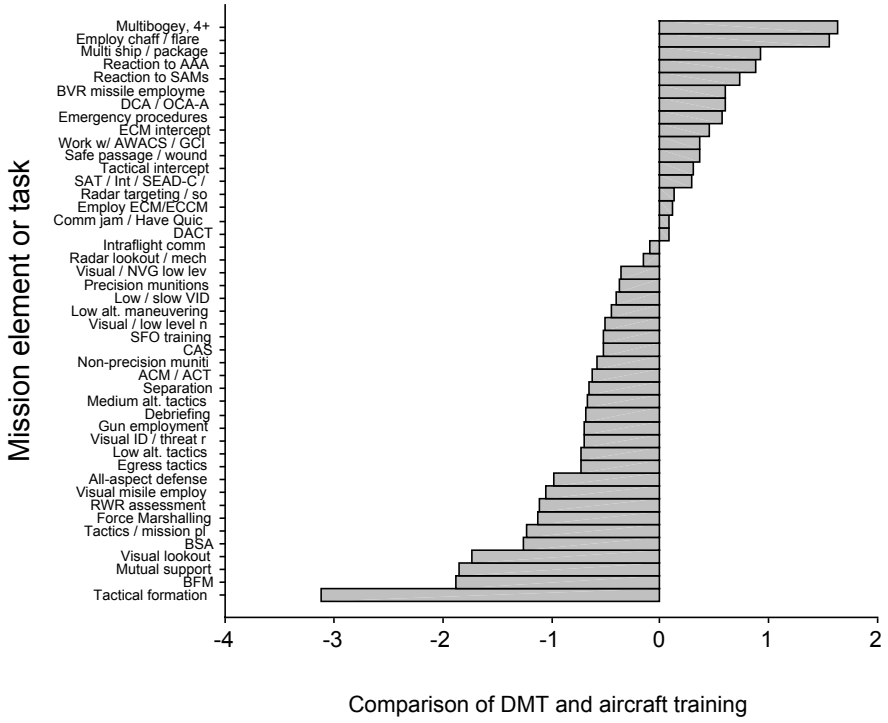


Figure 19. Differences between F-16 pilot ratings for aircraft training and DMT effectiveness

AWACS Performance and DMT Evaluations

AWACS team performance was rated by an AWACS instructor for Mission Briefing, Mission Execution, and Debriefing. Mean performance ratings for the SAT 1 and SAT 2 missions are depicted on Figure 20a. More detailed analyses of AWACS performance ratings are presented in Appendix C.

In addition to instructor evaluations, AWACS weapons directors were asked to rate the effectiveness of DMT overall and in comparison to large-force exercises such as Red Flag. Overall training effectiveness was assessed on a scale from 1 to 5 with the anchors:

1 = Completely useless

2 = Learned a little

3 = Somewhat beneficial

4 = Very useful

5 = Excellent training

Mean ratings are depicted on Figure 20b. In comparison to large-force exercises, 50% or more of the weapons directors participating in RoadRunner '98 rated DMT as providing equal or better training than flag exercises for all missions except CAS. Only 30% of weapons directors and air surveillance technicians rated DMT as providing equal or better training for the CAS mission. For the Interdiction and OCA missions, 70% of weapons directors rated DMT training as equal or more effective then flag exercises.

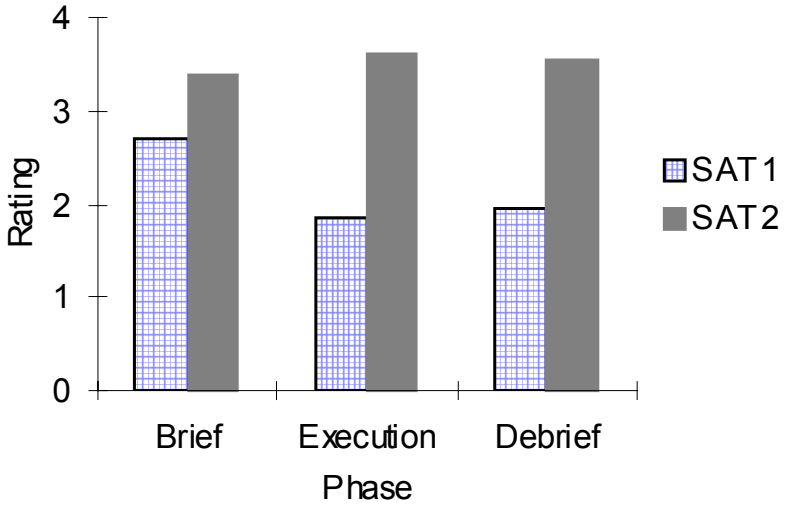
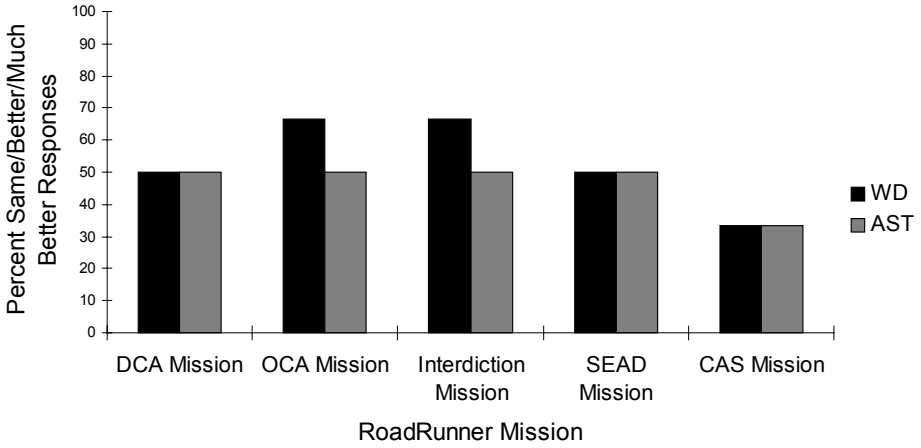


Figure 20. a) Mean AWACS mission performance ratings



b) AWACS training effectiveness ratings

Participant Critiques and Feedback

Pilots and AWACS controllers were asked to critique their experience in RoadRunner '98 and to suggest how DMT systems should be used in future training exercises. The feedback provided by participants can be grouped into three overall categories: best features and applications of DMT, system problems, and factors that reduced training effectiveness.

Best features and applications of DMT. The participants' overall evaluation was that the RoadRunner '98 exercise provided valuable experience performing combat missions and tasks that are infrequently practiced in the air. The most frequently cited strength of the training was the capability to employ as a four-ship formation against multiple, maneuvering targets. Pilots cited targeting and sorting, missile employment, communication, and building situation awareness as significant training benefits. AWACS crews also cited the communication with pilots as a strong point. Weapons directors were emphatic about the training value of briefing and debriefing with the Mission Commander even though these contacts were limited to fax and telephone; Air Surveillance Technicians were much less positive regarding debrief. According to the Weapons Directors, the major benefit of debriefing with pilots was receiving direct feedback on the quality and timeliness of their radio communication. F-16 pilots cited the replay and debrief system at AFRL, Mesa, as being valuable for increasing their skills at building situation awareness (see Figures 6 a and b). Pilots stated that the ability to simultaneously review the plan-view display and each cockpit's radar and RWR was beneficial in diagnosing errors. Replay of the stores management system was much less valuable and replay of the HUD was largely illegible. F-16 pilots also commented that the air-to-air scenarios that were presented after the main training mission was completed (see Appendix B) provided valuable training. After the first day of RoadRunner '98, the F-16 pilots asked if the short air-to-air scenarios could be recorded for replay and debrief and the day after that the AWACS teams asked if they could participate. Both pilots and AWACS teams stated that these brief scenarios provided excellent training for multiship, multibogey air combat. Participants stated that radar mechanics, communication skill, tactical execution, and situation awareness benefited from these scenarios. Participants further stated that opportunities to practice these skills on the training range were infrequent and that experience in DMT should significantly enhance their skills.

Recommendations for best applications of DMT focused on tasks that are well supported by DMT system capabilities and are infrequently trained in the aircraft. These tasks involve communication and coordination among multiple players and are not dependent on out-the-window visual imagery. Multiship, multibogey, beyond-visual-range air combat was cited by all participants as the best application for DMT. Pilots also cited threat reaction and all-aspect missile defense as potentially high payoff applications but that limitations in constructive forces in RoadRunner '98 limited training effectiveness. Air-to-surface ordnance delivery tasks that were major components of the RoadRunner '98 SAT and OCA A-G missions were cited as having low payoff because DMT visual capabilities limit training effectiveness and these tasks are frequently practiced in the aircraft. The ordnance delivery component of the RoadRunner '98 CAS mission was limited by the visual display system, however, coordination with the A-10 FAC was cited as highly beneficial. All participants recommended that DMT exercises be structured as two- or more-day events rather than a single simulator session. The multiple sessions provided opportunities to apply and reinforce lessons learned; however, the relationship among simulator sessions should be better coordinated than in RoadRunner '98.

System problems. The large majority of comments identified systems or simulations that did not operate correctly or like the real world. Many of these items could be corrected during RoadRunner '98 but others could not. Items that were corrected within an engagement included re-boresighting a head-tracker in an F-16/M2DART or restarting an image generator that failed. Items that could not be corrected but caused minor difficulties included switches that traveled in the incorrect orientation and a nonfunctional Data Entry Display in one F-16 cockpit. Other problems mentioned in critiques resulted in significant mission impacts. These include the communication problems between the cockpits and AWACS, communications failures within the AWACS simulator, and the F-16 replay system did not rewind or fast forward reliably. Fidelity of the F-16 RWR was cited as a serious limitation on training. The simulators' RWRs did not act like the pilots expected and as a result they were unable to use information from the RWR to effectively defend themselves.

Training effectiveness. Several issues were repeatedly mentioned as limitations to effective training using RoadRunner '98 systems. Two items generated most of comments regarding training effectiveness: visual display systems and the behavior of constructive forces.

The F-15 WTTs used at TACCSF provided only forward view, out-the window visual display that was combined with the HUD. Pilots found this system only useful for providing a horizon and an earth-sky frame of reference. Training effectiveness was limited to tasks that could be conducted inside the cockpit such as beyond visual range air engagement. The general consensus of the F-15 pilots was that the systems they experienced in RoadRunner '98 represented a step in the right direction but were not capable of providing useful training. The F-16 cockpits at AFRL/HEA provided a wide field-of-view, full field-of-regard display with high brightness and contrast. Pilots described the system as providing a high level of immersion into the battlespace particularly when integrated with the SGI Reality Monster image generator. Those who were familiar with the Red Flag training range found that they could easily navigate using the imagery provided by the M2DART/SGI system. Comments regarding the adequacy of this display for air-to-surface missions were decidedly mixed. Pilots stated that the wide field-of view helped support situation awareness and allowed them to employ many ordnance deliveries such as a pop-up attack.

Target resolution was not cited as a problem when the Designated Mean Point of Impact (DMPI) was surrounded by larger, easily seen, visual features such as runways and storage tanks. For the CAS mission, however, the targets were surface vehicles such as T-72 tanks; to increase visibility, the tanks were moving across the terrain and generating dust trails. Many pilots noted that even with the dust trails, the tanks could not be detected from altitude and that they often began an attack against the coordinates provided by the A-10 FAC without a target in view. There was a difference of opinion on this point between more and less experienced F-16 pilots. The less experienced pilots cited the inability to clearly detect the target from altitude as limiting the training value of the M2DART system. More experienced pilots, however, noted that they often are unable to see a tank-sized target from altitude when the weather is less than ideal. Under these conditions, pilots must use the cues provided by the FAC describing the target's location with respect to larger, more easily seen visual features. These pilots cited the M2DART as providing sufficient resolution for training CAS missions as the pilots were required to use all the visual cues in the environment to locate their target. The A-10 pilots, who flew a cockpit equipped with an earlier generation DART visual system, evaluated the simulation as fully satisfactory and supported performance of their mission as a FAC.

The most significant problems for the M2DART were in the air-to-air environment. Pilots consistently complained that they could not determine the aspect orientation of other aircraft at realistic distances. This limitation prevented them from maintaining tactical formation, conducting within-visual-range engagements, and maintaining visual mutual support. The difficulty was that the red-blue-white light system described earlier supported pilots' ability to detect other aircraft but prevented them from discriminating which way the other aircraft's nose was pointing, whether the aircraft was flying wings-level or turning, and whether it was approaching or moving away. This limitation was a source of frustration that did not decrease over the five days of RoadRunner '98.

The second major concern expressed in pilot critiques was the behavior of the constructive forces. Both airborne and surface threats were cited as unrealistic with respect to modeling the actual systems and the behavior of red force warfighters. Comments regarding physical modeling included the long range and uncanny accuracy of red missiles, difficulty in defeating red missiles, the speed and turning capabilities of red aircraft, their apparently unlimited fuel reserves, and the ability of surface threat systems to detect and track blue aircraft without stimulating their warning systems. Comments regarding the behavior of red forces focused on their very high level of situation awareness, speed with which red pilots were able to sort a formation and launch missiles, and their ability to retarget a blue formation after losing radar lock. These factors were frequently cited as a major limitation on training effectiveness as pilots were unable to employ defensive tactics against threats that had, "360° radar, mach-10 missiles, and perfect situation awareness."

In addition to visual displays and constructive forces, other systems were cited as limiting training effectiveness. One comment made by both pilots and AWACS teams was that the simulated radars worked much better than actual systems. Pilots and weapons directors could detect targets at long range and track them continuously without losing track due to ground clutter.

F-16 pilots frequently mentioned that the fire control radar's Track While Scan (TWS) mode operated much better than in the aircraft and could encourage over-reliance on this mode. Participants stated that having simulated systems that work too well reduces training

effectiveness since it eliminates much of the fog and friction of war. Conversely, while communication breakdowns between pilots and AWACS were cited as system problems, some pilots noted that these failures were representative of real-world communications thus contributing a desirable quantity of fog and friction.

Another issue that reduced training effectiveness was the amount of time available for mission briefing and system setup after an exercise began particularly for AWACS teams. While F-15 pilots did not cite the assigned time line as a problem, F-16 pilots often wanted more time between unfreeze and push. AWACS crews consistently stated that they needed more information from the pilots during briefing and more time to set up their radar scopes after the mission started. AWACS crews also stated that the procedures for declaring a target as friendly or hostile were unrealistic and that mission scenarios were designed for training pilots with inadequate consideration of AWACS crews. Air surveillance technicians were especially critical on this point as they had only limited roles in the RoadRunner '98 scenarios.

A third issue dealt with the schedule (see Table 1). Flying two different missions per day that were independent from each other was cited as not providing focused training. Participants suggested reducing the variety of missions or generating an integrated, four-day war as ways to increase training effectiveness.

DISCUSSION

The specific objectives for RoadRunner '98 were to: (a) demonstrate DMT capabilities necessary for combat mission training, and (b) validate a research approach for DMT training effectiveness studies. Data were collected during RoadRunner '98 to address these objectives in two ways: mission accomplishment and team performance. Analyses of mission accomplishment include whether missions could be successfully accomplished in the DMT environment, what systems or capabilities enhanced or degraded from mission accomplishment, and participant evaluations of the training value for these missions. Analyses of mission performance include changes in measures of mission success and instructor or supervisor evaluations of team performance.

Missions and Mission Tasks

RoadRunner '98 was designed to assess how well prototype systems could support real-time simulator-based training for a variety of composite force missions over a secure, wide-area network. In all of the RoadRunner '98 missions other than CAS and DCA, F-15s provided a pre-strike sweep while the F-16s delivered ordnance against a defended surface target and AWACS provided radar surveillance and battle management. Other blue force elements such as SEAD aircraft were provided constructively. In the CAS mission, the F-16s and the A-10 attacked a formation of red force tanks defended by AAA while the F-15s were engaged in an independent DCA scenario supported by AWACS. In the DCA scenario, the F-15s and F-16s each defended a lane of airspace from red force airborne threats while supported by AWACS. In all cases, the missions were completed on schedule and as planned. There were some delays and on occasion a virtual player fell off-line and the mission proceeded without them. Overall, RoadRunner '98 demonstrated that these composite force missions can be conducted using current DMT systems. More detailed examination of the data provides insight regarding which systems enhanced and degraded mission accomplishment and whether the exercise provided useful training.

DMT systems and mission accomplishment. Four categories of DMT systems affected mission accomplishment: networking and communications, weapons systems simulation, visual displays, and constructive forces.

Networking and communications using DIS protocols and dedicated, high-bandwidth links fully supported RoadRunner '98 missions. At no time did communications bandwidth or reliability degrade DMT training effectiveness for all entities other than AWACS. Due to non-availability of high-bandwidth communications, a work-around solution was created especially for the RoadRunner '98 exercise using standard telephone lines. This system suffered from reliability problems although these decreased over the course of the exercise. Training effectiveness evaluations conducted subsequent to RoadRunner '98 have demonstrated that AWACS operations can be fully supported by standard DIS communications protocols and high-bandwidth links (see Crane, 1999). It must be noted, however, that the networking system was used to support only the real-time execution of the mission. Mission planning, briefing, replay, and debrief were conducted using an independent telephone system.

Weapons systems and aircraft systems include simulation of the airframe and propulsion systems together with avionics and weapons. Simulation of systems that affected only individual aircraft functions such as handling characteristics were rarely cited as problems. Cockpit systems that involved interactions among different entities were frequently cited as degrading mission accomplishment. These include simulation of air-to-air radar that at times performed both much better than and much poorer than the actual radar, RWR performance that did not meet expectations, weapons that were at times both more and less effective than specified by doctrine, and ineffective countermeasures. The critique that air-to-air radar performance was superior to the actual aircraft's radar reflects problems in both the virtual environment and on the live, training range. In the RoadRunner '98 simulation, effects of ground clutter were not modeled resulting in unrealistic radar performance at low altitude. Although contrary to pilot expectations, detection ranges for threat aircraft at medium altitudes and higher were valid for the threat aircraft modeled in the scenarios, i.e., MiG-29s and Su-27s. These aircraft have considerably larger radar cross sections and therefore longer detection ranges than the F-16s that typically play the role of threat aircraft on home station training ranges. For these threats, pilot expectations regarding air-to-air radar performance were influenced by constraints on range training. Another source of difficulty was the myriad of systems on-board each entity that could affect another entity. One aircraft's radar, for example, will detect and track another aircraft and at the same time stimulate the target aircraft's RWR. Further, if fired upon by a radar-guided missile, the pilot of a target aircraft can defeat that missile using countermeasures such as chaff. Alternatively, the pilot can attempt to defeat the attack by breaking the missile's radar lock, fly behind a mountain, or defeat the missile kinematically by aggressive maneuvers at end-game. During RoadRunner '98, fighter aircraft were generated from several sources both virtual and constructive. Many sources were legacy systems that were designed for other purposes and modified for participation in multiplayer, real-time simulation exercises. Some of these simulations were, for example, sensitive to chaff while others were not and some radar models could be occluded by terrain while others could "see through mountains." While these simulations were fully adequate for their original purposes, they lack capabilities required for incorporation into DMT for aircrew training. The lack of consistency among the interactions between players seriously degraded mission accomplishment during RoadRunner '98 as participants were unable to predict whether a given action would or would not successfully achieve an intended goal.

Visual display systems were frequently cited as both enhancing and degrading mission accomplishment. The F-15 WTTs were equipped with only a forward view display. These cockpits supported beyond-visual-range weapons employment but little else. F-15 pilots cited only in-cockpit tasks such as radar sorting and employment and non-visual tasks such as intraflight communications as being well trained in DMT.

The F-16 MTTs were equipped with a full field-of-view display. F-16 pilot evaluations indicate that these systems supported more training tasks than the F-15 WTTs such as reaction to SAMs and surface attack tactics missions. Like the F-15 pilots, however, the F-16 pilots rated in-cockpit and non-visual tasks as being most effectively trained using DMT. The most significant limitation of the F-16 visual display systems was the pilots' inability to determine the aspect of another aircraft at real-world ranges. Pilots had difficulty engaging red aircraft and supporting blue aircraft. F-16 pilots rated tactical formation as being the task most effectively trained in the aircraft and the least effectively trained in DMT. The white-red-blue colored light system used during RoadRunner '98 was useful but not an effective substitute for real-world target resolution. The capability of the M2DART to support air-to-surface training varied with the target and the pilots' expectations. For some missions, targets were selected to provide large, easily seen visual cues such as a runway intersection on an airfield. The pilots did not find using the visual display systems for these missions to be problematic. For smaller targets such as tanks used in the CAS mission, feedback was mixed depending on pilot experience and expectation. Overall, factors other than target visibility were responsible for lack of mission accomplishment on air-to-surface missions. These factors include inability to effectively use terrain masking and inability to maintain tactical formation or mutual support with other F-16s.

The M2DART's full field-of-regard visual display system was also cited as providing the most immersive and engaging simulation the F-16 pilots had ever experienced. The wide field-of-view enhanced the pilots' ability to maintain aircraft control by using their peripheral vision to keep track of the horizon, and the special effects such as explosions enhanced situation awareness. Pilots who flew the M2DARTs that were equipped with Silicon Graphics photo-based Reality Monster image generators repeatedly mentioned the realism of the display as enhancing situation awareness for the environment. Pilots who were familiar with the Red Flag training range could easily navigate using the photo-based imagery particularly at medium altitude.

Constructive forces. Like the visual display systems, the behavior of constructive forces both enhanced and degraded from training effectiveness. F-15 and F-16 pilots were near unanimous is rating air combat in a multi-bogey environment as the task most effectively trained in DMT. The capability of DMT to provide multiple, maneuvering MiG-23, -29, and Su-27 aircraft was the most highly rated training feature of the systems in RoadRunner '98. The behavior of these target aircraft and their weapons was also among the most severely criticized aspect of RoadRunner '98. The main thrust of the critiques was that the red force aircraft did not die when they should have and had unrealistic combat capabilities including radar coverage, situation awareness, ability to attain and maintain radar lock, turning rate and radius, and sustained airspeed. Many of these criticisms were traced in post-exercise reviews to incomplete threat models. For example, the MiG-29s could maintain very high airspeed for the duration of an exercise. Post-exercise analysis revealed that the MiG's fuel did not decrement with time and airspeed so that the threat aircraft, in effect, flew using full afterburner all the time. A second example was the unrealistically high probability of a kill (P_k) for the constructive SAMs.

Analyses revealed that the missiles did not have unrealistic ranges or sensor capabilities but that environmental effects which would reduce the missiles' P_k in the real world such as the effects of terrain clutter were not modeled. The effect of these incomplete threat models was to reduce the virtual players' ability to defend themselves. Overall, the incorporation of constructive forces was among the most positive aspects of DMT in RoadRunner '98. Problems with the constructive-force models were among the most significant limitations in the exercise. Overall, the results of RoadRunner '98 demonstrate that with some areas for improvement, prototype DMT systems are capable of supporting a variety of composite force missions.

Training effectiveness and utility. A second area of concern for DMT is training effectiveness and utility. The focus of this concern is not whether DMT can support training for a given mission or task but whether there are sufficient benefits to justify using DMT for training that mission or task. Three sources of data from RoadRunner '98 reflect on this issue: the availability and sufficiency of aircraft training for a given mission or task, the effectiveness of DMT for providing training, and the design of training events and instruction support systems.

F-16 pilots noted several tasks or mission elements that are not well trained in the aircraft. These include tasks that cannot be simulated on a training range for reasons of safety (e.g., reaction to AAA), security (e.g., employment of ECM/ECCM), and lack of resources (e.g., multibogey engagements). Other tasks such as tactical formation and visual missile employment were rated as very well trained in the aircraft. Similarly, F-16 pilot ratings of training effectiveness in DMT show that some tasks are well suited for training in DMT such as radar targeting and sorting and that other tasks such as tactical formation are not. Combining pilot ratings of effectiveness for aircraft training and DMT reveals some mission tasks that are well supported by DMT and infrequently trained in the aircraft. Multibogey (4+) engagement was the DMT task highest rated by both F-15 and F-16 pilots. F-16 pilots also included threat reaction, employment of chaff and flares, multiship package employment, and work with AWACS as being both well supported by DMT and only intermittently trained in the aircraft due to safety, security, and resource constraints. These data indicate that DMT training utility for pilots is a function of both the quality of the training provided in DMT and the availability of aircraft training. Similar results can be seen for AWACS teams. Compared to Red Flag, Weapons Directors and Air Surveillance Technicians rated DMT as providing effective training for missions other than CAS. In addition, Weapons Directors rated DMT as more effective than Red Flag for the OCA and Interdiction missions in which blue forces fly deeply into enemy controlled airspace. For carefully selected tasks and missions, therefore, DMT can effectively complement aircraft training.

A second factor that affects training effectiveness and utility is the design of training events and instructional support systems. In order to assess the capabilities of DMT to support training for a variety of missions, RoadRunner '98 incorporated six different missions within four days. One F-16 pilot referred to this schedule as a "smorgasbord of missions" that detracted from training effectiveness. In follow-up interviews, AWACS teams stated that incorporating missions into an evolving war scenario would increase the training value of a DMT exercise. Alternatively, F-16 pilots recommended repeating missions morning and afternoon. This schedule would give them the opportunity to immediately apply the lessons learned from the morning training session. This compares with aircraft training in which a pilot may learn a valuable lesson but not experience a similar mission for weeks or months.

RoadRunner '98 participants also cited mission briefing, replay, and debriefing as significant determinants of training effectiveness. AWACS Weapons Directors stated that the opportunity to brief and debrief with the pilots immediately before and after missions greatly enhanced training effectiveness. This compares with an AWACS aircraft training mission in which only the Senior Controller will debrief with the Mission Commander on the telephone several hours after the mission is over and the AWACS has landed.

Replay and debrief in RoadRunner '98 consisted of independent replays of a mission followed by discussions over speaker telephones between F-15, F-16, and AWACS teams. Although these discussions became heated and confrontational at times, the controllers agreed that they learned a great deal about what information pilots need and when they need it. The F-16 pilots also cited quality of the replay system as enhancing training effectiveness. The replay system at AFRL/HEA allowed the flight leader to review each of the F-16s' radars. This capability allowed the flight leader to diagnose and remediate errors in radar mechanics or failures to follow the briefed search, targeting, and sort plans. Replay of radio communications for all players allowed participants, particularly the flight leaders and the AWACS controller, to evaluate and remediate their calls. Initially, participants focused on making sure that their calls were correct, complete, concise, and in accordance with Air Force standards. As the week progressed, the emphasis changed to insuring that communications enhanced the flight's overall situation awareness. RoadRunner '98 participants agreed that telephone communication for debrief was insufficient and recommended that systems be provided in DMT exercises that would allow warfighters at multiple locations to participate more extensively in mission replay and debrief. Video teleconference capabilities and interactive whiteboards were frequently suggested options.

Team Performance

Team performance in RoadRunner '98 was assessed by instructor ratings of team skills and objective measures of mission accomplishment during the first and last missions. Instructor rating data is presented only for F-16 pilots and AWACS crews. As there were only six F-15 pilots participating in RoadRunner '98, they could not form fixed teams that worked together during the week. The first and last missions conducted during RoadRunner '98 were designed to be similar and very demanding. These surface-attack tactics missions required the F-15s to fly a pre-strike sweep and the virtual F-16s to attack targets located at an airfield that was defended by both surface and airborne threats. Bomb score (miss distance) improved from SAT 1 to SAT 2 and losses to both surface and airborne threats decreased. The decrease in red air kills to zero was caused by a large reduction in the number of engagements between the virtual F-16s and red air threats. Between the first RoadRunner '98 mission and the last, F-16 pilots increased their skills at working with the AWACS and F-15s to avoid engaging enemy fighters and to focus their resources on putting bombs on target.

AWACS instructor ratings of team performance increased from the first mission to the last with the greatest increase in mission execution. F-16 instructor ratings of overall mission performance, communication, situation awareness, and crew coordination also increased after four days of DMT experience. Performance on all high-level skills assessed using the TOM scales improved for all teams. Review of each team's overall performance ratings and skill ratings by mission phase, however, shows greater variability. Team C, for example, demonstrated nominal performance for several mission phases including brief and debrief during

SAT 1. Performance for these phases did not increase over the week of RoadRunner '98 while teams A and B showed considerable improvement. Review of the TARGET findings particularly for team B shows which specific behaviors were changed after four days of DMT. Team performance as assessed by the TARGET scales shows that experience responding to specific scenario events enhanced team skills such as coordination between pilots and AWACS. Overall, instructor ratings of team performance using the TOM/TARGET rating scales are in agreement with the performance measures, questionnaire data, and direct feedback from participants. Communication skill was cited as benefiting from DMT experience by both pilots and AWACS crews. Other skills that benefited from DMT experience were maintaining mutual support, adhering to the mission plan, developing situation awareness, and decision making.

Summary

The results of the RoadRunner '98 DMT exercise show that prototype DMT systems are capable of providing composite force training over a wide area network for a variety of missions. The data further show that DMT training using current systems is most effective and useful for multiship, multibogey air combat with AWACS support. DMT training effectiveness can be increased for other missions and tasks through improvement of DMT technologies, notably visual display systems, constructive forces, and brief/debrief systems. Results from RoadRunner '98 also demonstrate that training effectiveness in DMT can be assessed through a combination of objective measures of mission performance, instructor evaluations, and participant feedback. By examining these different measures of effectiveness, system designers and instructors can identify the tasks and skills that are well suited to DMT, develop simulator and instructional support systems to improve training for these skills, and design DMT scenarios that are tailored to enhance specific warfighter combat skills.

CONCLUSIONS AND RECOMMENDATIONS

The primary conclusion that can be drawn from the RoadRunner '98 exercise is that current DMT technologies are capable of providing effective, warfighter training in simulation that complements aircraft training. Areas for improvement in both technologies and instructional design were identified and recommendations are offered regarding DMT systems and exercises.

Areas for Improvement

No major shortfalls or showstoppers occurred during RoadRunner '98 but many systems and strategies were identified that limited training effectiveness.

DMT systems. Improvements to the following systems should result in significant increases in DMT effectiveness.

Interactions between entities. Virtual and constructive entities in RoadRunner '98 did not consistently interact as they would in the real world. Simulation fidelity in DMT requires that the full spectrum of interactions of offensive and defensive interactions between players are correctly and consistently modeled including environmental effects.

Visual display systems. High-fidelity out-the-window visual display systems are required for all aircraft. These displays are required for both effective training of team skills

such as maintaining tactical formation and mutual support and for immersing participants into the synthetic environment. For fighter aircraft, visual display systems must be able to support target detection, aspect determination, and recognition at real-world ranges without introducing artificial cues.

Behavior of constructive forces. The behavior of the constructive forces used in RoadRunner '98 can be improved in three areas: flight modeling of aircraft and missiles, electronic interactions between entities, and human behavior models of pilots and air defense crews. Flight models include speed, range, turning, and fuel capabilities. Electronic interactions include radar detection and tracking, radar warning systems, effects of countermeasures, and maneuvers to break radar lock. Improving human behavior models of enemy warfighters should include better modeling of red force commit/abort criteria, shot doctrine, defensive tactics, and varying levels of skill among members of a flight. Improvements to behavior models, however, should be lower in priority than improving flight models and the fidelity of electronic interactions. Removing unrealistic behaviors of constructive forces will have greater near-term payoff than improving human behavior models.

Mission brief and debrief. Effective use of DMT requires more than flying simulators together over a wide-area network. Warfighters must be able to plan, brief, replay, and debrief a mission as individuals, teams, and as a composite force. Systems are required that will support virtual interactions among teams during mission brief and debrief as well as during mission execution.

Training scenarios and strategies. RoadRunner '98 was designed as an evaluation of the potential of DMT rather than as a training exercise. Based on participant feedback from RoadRunner '98, the following recommendations can be made regarding the design and conduct of DMT exercises.

Selection of mission tasks and skills. The missions, tasks, and skills to be trained in a DMT exercise should be selected on the basis of three criteria: capabilities of DMT systems to support the proposed training, availability of aircraft resources for the proposed training, and the anticipated benefits of DMT experience. DMT can effectively complement aircraft training when aircraft training is constrained by resource, safety, and security limitations. DMT can provide experience for tasks that are rarely practiced in the air or, DMT can provide relevant experience for warfighters before they participate in resource-intensive training events.

Time on task and application of lessons learned. DMT exercises should be designed to maximize the amount of time spent on the most demanding segments of a mission. Starting a scenario in mid-flight and terminating after training objectives have been achieved allows teams to experience multiple examples of a given problem. Further, exercises should be designed so that the lessons learned in one DMT session can be applied during the following sessions.

Deliberate instruction in a dynamic environment. DMT is more than mission practice. Instructors and flight leaders must establish specific training objectives for a given team and training event. Based on these objectives, instructors should identify scenario events that will elicit or demand the selected skills. DMT designers can then generate multiple examples of scenarios that incorporate these trigger events. Using this instructional strategy will allow instructors to tailor DMT exercises to meet the needs of specific teams and individuals.

Recommendations for Future Exercises

RoadRunner '98 was designed to evaluate and demonstrate the training potential of DMT for composite force training. Based on experiences gained from RoadRunner '98, more focused training evaluations have been undertaken at AFRL/HEA (see Crane, 1999; Jensen & Crane, 1999). The objective of this research is to develop training systems and strategies for F-16 pilots and to assess the impact of DMT on an existing training syllabus. In addition to the systems improvements described above, the following recommendations are offered to the developers of future composite force, DMT exercises.

Configuration management. A single agency with access to the appropriate models and data should be tasked to insure that interactions among all players, virtual and constructive, are consistent and valid. Updates and modifications to models and data must be provided to all users and their incorporation into DMT exercises assured by the configuration management agency.

Central servers. To insure consistency of effects and to ease the burden of configuration management, central servers for weapons modeling, electronic interactions, and environmental effects should be incorporated into the DMT network.

Participants and training objectives. A major training payoff of the RoadRunner '98 exercise was the opportunity for improving inter-team communication and coordination. AWACS controllers and pilots all benefited from the experience gained in RoadRunner '98. Future composite force DMT exercises could be designed to bring together forces that are representative of contemporary air operations including SEAD elements, force protection, surface attack, AWACS, Modular Control Equipment ground based weapons controllers, Rivet Joint, Unmanned Air Vehicle, and other information warfare assets. The great strength of DMT is the capability to complement current training programs and large force exercises with opportunities for a wide variety of warfighters to interact in an unrestricted environment with scenarios designed to exercise specific tasks and skills.

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APPENDIX A

Mission Data

This appendix contains:

1. The air order of battle, and

2. The following data for each of the seven missions in RoadRunner '98:

    - Mission map including threat laydown and list of programmed red force actions. This map was available to white cell and instructors only, not participating pilots or AWACS teams.

    - Air tasking order (ATO)

    - Special instructions (SPINS)

Air Order of Battle

Tolicha: 1x each squadron of Flanker and Fulcrum aircraft available for combat air patrols (CAPs). Typical CAPs include 2-ships of Mig-29s or Su-27s to the south and 4-ships of Mig-29s to the north.

Tonopah: 1x squadron of Mig-23 Flogger aircraft in the ground attack role, carrying infrared (IR) missiles for self-protection. 1x squadron of Mig-29 used periodically in CAPs to the east.

Tonopah Test: Mig-29 Fulcrum on 10-minute alert at any time. 1-, 2-, or 4-ships of Mig-29s have been seen capping to the north. Also, 2-ships of Fulcrum have been seen capping to the east.

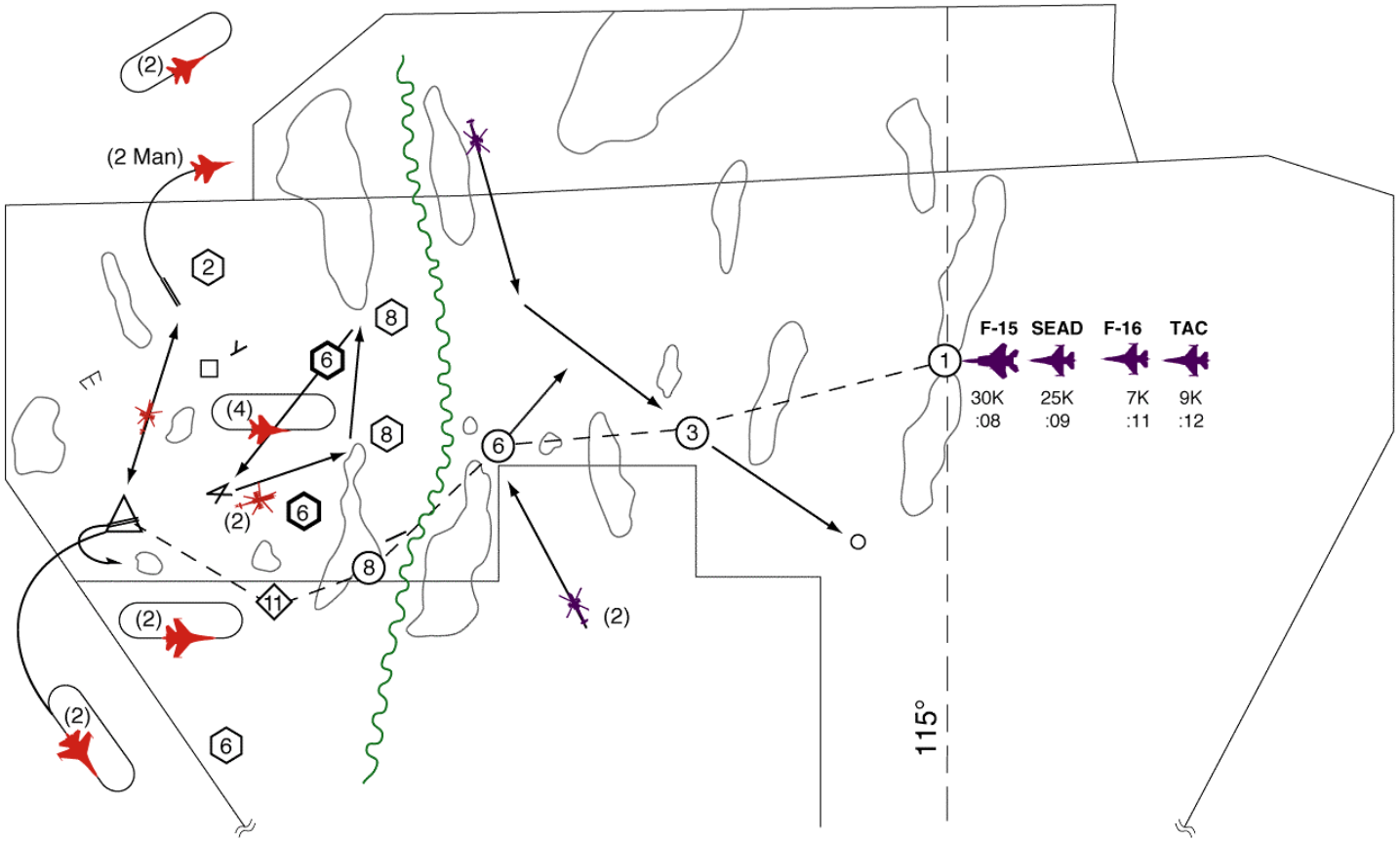
Helen: Hind helicopters operating in the resupply / transportation role.

Kawich: No operational aircraft, however, it is capable of supporting fourth-generation fighters.

Korea: No operational aircraft.

Depot Airfield: Transport aircraft.

SAT 1 Shields Up



INITIAL PICTURE
2 x MiG-29 — North CAP
4 x MiG-29 — Center CAP
2 x Su-27 — South CAP
2 x Mi-24 — Target Area

SCENARIO INPUTS
:05 — 2 x MiG-29 (Man) takeoff Tonopah
:08 — 2 x AH-64 takeoff Box
:11 — Mi-24 takeoff Tonopah
:12 — 2 x MiG-29 (Center CAP) attack
:14 — AH-64 takeoff Bear Paw
:17 — 2 x MiG-29 (Center CAP) attack
:17 — 2 x Su-27 takeoff Tolicha
:20 — 2 x MiG-29 (Man) takeoff Tonopah

TARGETS
Tolicha Airfield

TOTs
F-16 :22
TAC :23:30

SAT 1 ATO

```
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Day 1 - Tuesday (AM)
Pre-Test

Note: Some participants will be flying SAT 1 first and some will be flying SAT 2 first as the pre-test. Those personnel flying SAT 1 for the pre-test will fly SAT 2 for the post-test and vice versa. The following information will display when there are differences between SAT 1 and SAT 2.

Pre-test Scenario (either SAT 1 or SAT 2): Day 1 of airstrikes. After long deliberations with the United Nations, the president of the hostile country has refused to pull troops out of our ally country. Today begins a series of air strikes designed to deny the hostile nation's use of vital air assets that could threaten our forces.

Commander's Intent: My intent is to deny the use of Tolicha airfield by fourth-generation aircraft, specifically Flanker and Fulcrum, that are currently based out of Tolicha. These are high priority air threats that may hamper our efforts in later airstrikes.

Target and Target Significance: Tolicha Airfield communications tower, pump house, and runway are to be targeted to deny Flanker and Fulcrum aircraft from utilizing support facilities and scrambling prior to coalition airstrikes.

Operational Surface Threats (SAT 1): #1, #3, #5, and #8 are operational. 2x SA-8s have been active along the forward edge of the battle area (FEBA). Last known locations of the SA-8s were 3745N 11615W and 3730N 11615W.

Air Situation (SAT 1):

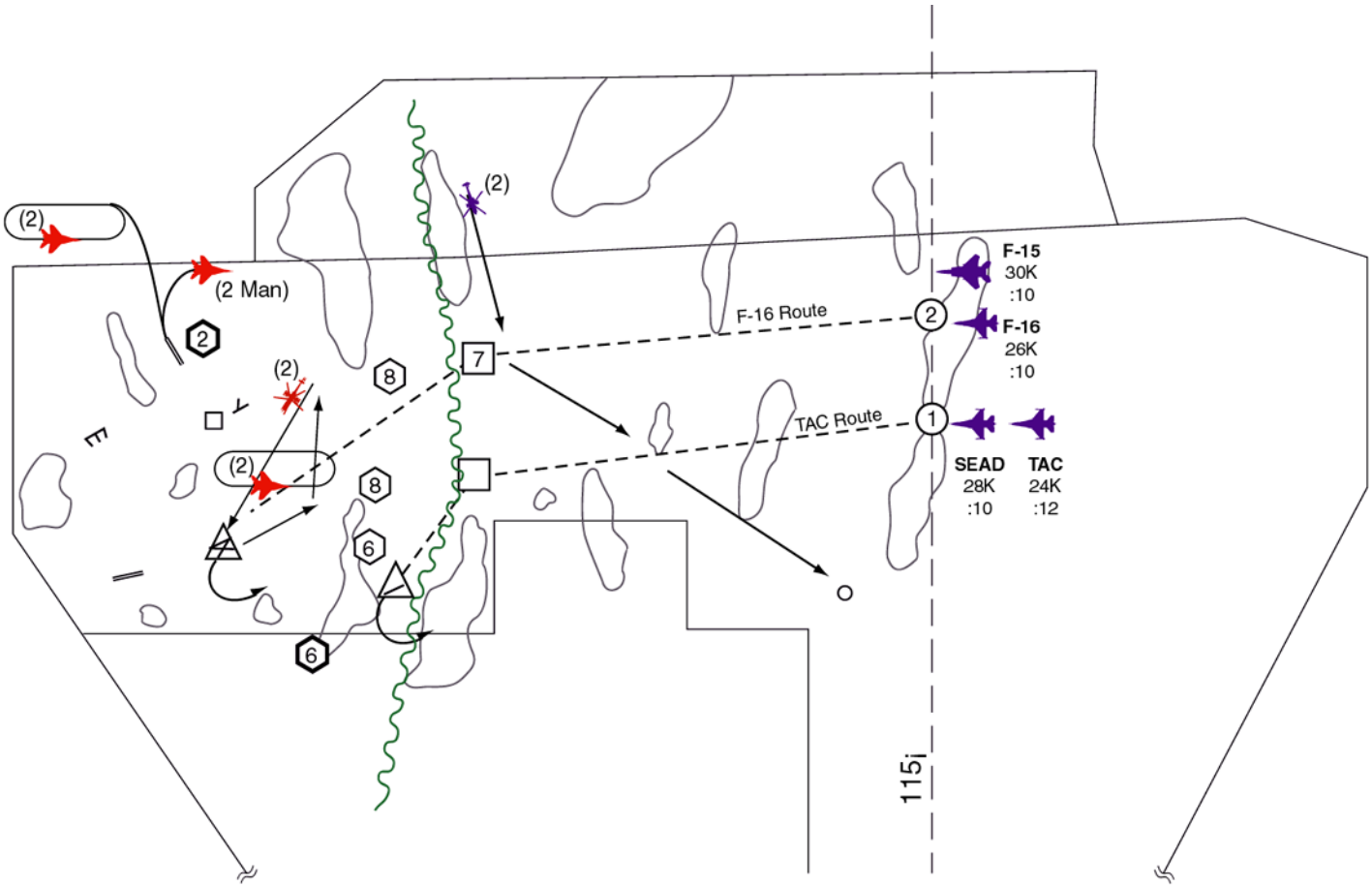
Numerous CAPs have been set up in preparation for possible hostilities, those include both Mig-29s and Su-27 out of Tolicha and Mig-29 out of Tonopah Test.
Hind helicopters flying from Tonopah Test to Tolicha and back are transporting aircraft parts and munitions.
2x Hind helicopters flying out of Helen airfield are resupplying and transporting troops and munitions along the FEBA as close as 12 NM from the FEBA.

Routes (SAT 1):

4x F-16CJ (Shooter 41): 1, 3, 6. . . split into two elements
- 2-ship F-16CJ (Shooter 41) against Miller
- 2-ship F-16CJ (Shooter 43) against Foster

8x F-16 (Viper 11 and Snake 21): 1, 3, 6, 8, 11, Target: Tolicha, South egress back to 11
4x F-15 (Cylon 51): Push from steerpoint 1 – proceed as briefed by the mission commander

OCA Shields Down



INITIAL PICTURE
2 x MiG-29 Ñ Center CAP
2 x Mi-24 Ñ Target Area

SCENARIO INPUTS
:12 Ñ 2 x MiG-29 (Man) takeoff Tonopah
:14 Ñ 2 x AH-64 takeoff Bear Paw
:14 Ñ 2 x MiG-29 takeoff Tonopah to North CAP
:15 Ñ 2 x MiG-29 (Center CAP) attack
:17 Ñ Unknown SA-6 Kawich Valley active
:22 Ñ 2 x MiG-29 (Man) takeoff Tonopah

TARGETS
Mt Helen Airfield (F-16)
Kawich Airfield (TAC)

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Day 1 - Tuesday (PM)
OCA

Commander's Intent: My intent in afternoon airstrikes is to deny the use of Helen and Kawich airfields. I intend to render both Helen and Kawich airfields unusable in the event the hostile nation elects to use these locations to forward deploy strike or CAS aircraft to threaten operations along the FEBA.

Target and Target Significance: Helen and Kawich airfield DMPIs include runways, taxiways, and runway intersections.

BDA: Surface threats #3 and #5 were suppressed by F-16 SEAD assets during the morning airstrikes. Threat #8 is unlocated – it is assessed to be in travel mode.

Operational Surface Threats: #1 remains operational from earlier in the day. #6 is a new, high priority SA-6 threat in the vicinity of the FEBA. 2x SA-8s have been identified as operational along the FEBA. The last known locations of the SA-8s were 3745N 11615W and 3730N 11615W.

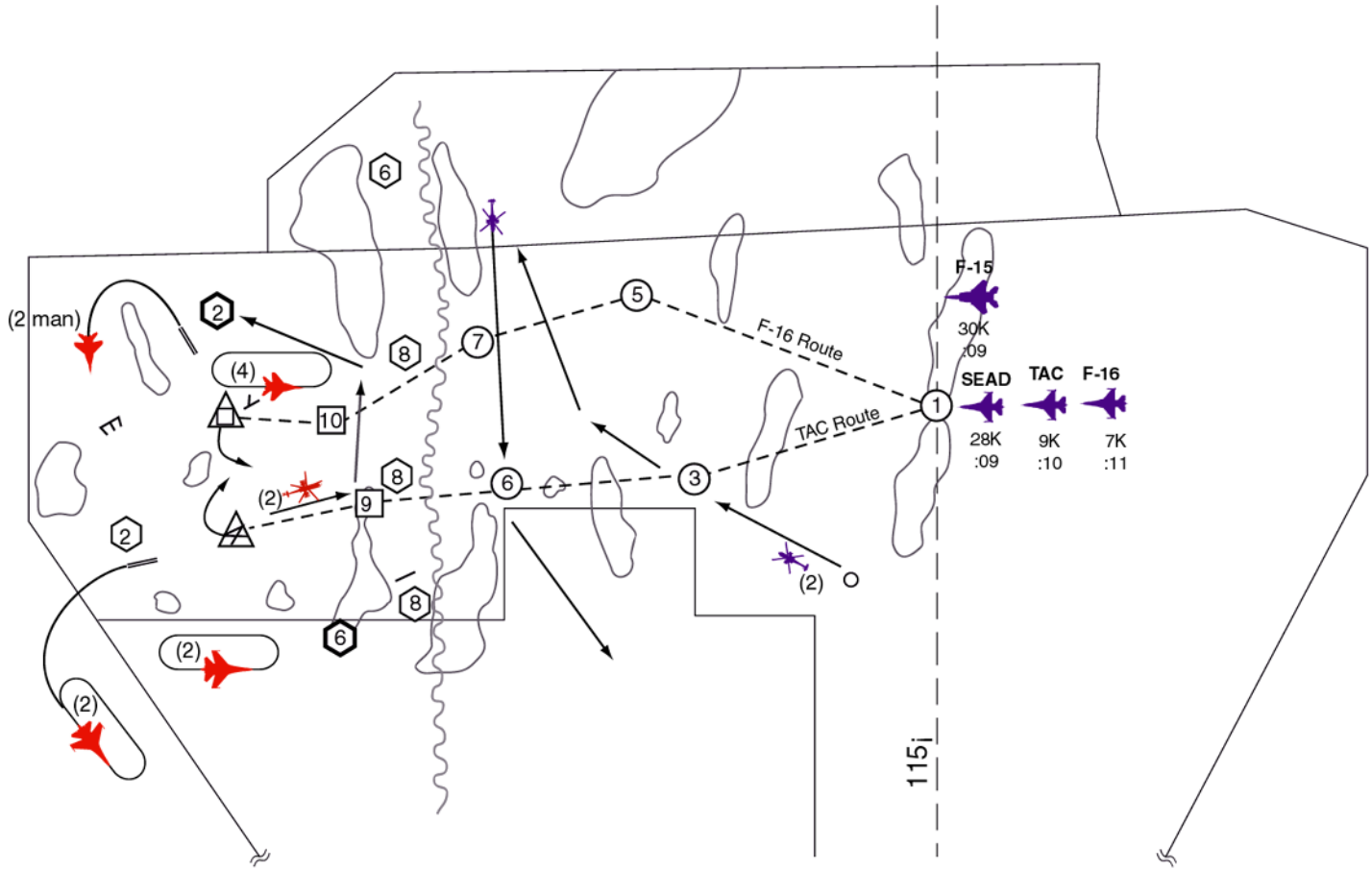
Air Situation:

2-ship Mig-29 caps active out of Helen and Tonopah airfields.
2 Hind helicopters continue to conduct resupply and transportation of troops and munitions out of Helen airfield.

Routes:

4x F-16CJ (Shooter 41): 1, IP (Belted Peak) . . . split into two elements against Falstaff and Amstel
4x F-16C (Viper 11): 2, IP is 7, Tgt: Helen Airfield, egress south to steerpoint 8, egress east
4x F-16C (Snake 21): 1, IP (Belted Peak), Tgt: Kawich Airfield, egress south and east
4x F-15 (Cylon 51): Push from Steerpoint 2, then proceed as mission commander directs

Interdiction Shields Down



INITIAL PICTURE
4 x MiG-29 Ñ Center CAP
2 x Su-27 Ñ South CAP
2 x Mi-24 Ñ Target Area

SCENARIO INPUTS
:07 Ñ 2 x AH-64 takeoff Alamo
:12 Ñ 2 x MiG-29 (Man) takeoff Tonopah
:12 Ñ 2 x MiG-29 (Center CAP) attack
:14 Ñ AH-64 takeoff Bear Paw
:15 Ñ 2 x MiG-29 (Center CAP) attack
:16 Ñ 2 x Su-27 takeoff Tolicha for Southern CAP
:21 Ñ 2 x MiG-29 (Man) takeoff Tonopah

TARGETS
Storage Depot (F-16)
Mt Helen Airfield (TAC)

INTERDICTION ATO

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Day 2 - Wednesday (AM)
Interdiction

Scenario: During a temporary cessation of coalition airstrikes in the morning, the enemy took the opportunity to send strike aircraft to attack our forward operating bases. Coalition forces will resume offensive action toward the hostile nation.

Commander's Intent: My intent today is to remove the enemy ground troop's ability to resupply with weapons and munitions and repair with spare parts. Also, with the previous day's airstrikes to airfields considered vital to the enemy nation, I will also remove their capability to repair damaged aircraft with spare parts.

Target and Target Significance: Targets include buildings at a storage depot and bunkers at Helen Airfield. Buildings in the storage depot will be targeted to deny the enemy the ability to resupply army troops. Bunkers at Helen Airfield will be targeted to deny the enemy the use of munitions, which we suspect supports ground troops.

BDA: #4 was effectively destroyed by SEAD assets. #1 remains active.

Operational Surface Threats: #1, #2, #6, and #7 are operational. 3x SA-8s have been active along the FEBA. The last known locations of the SA-8s were 3745N 11615W, 3730N 11615W, and 3715N 11615W.

Air Situation:

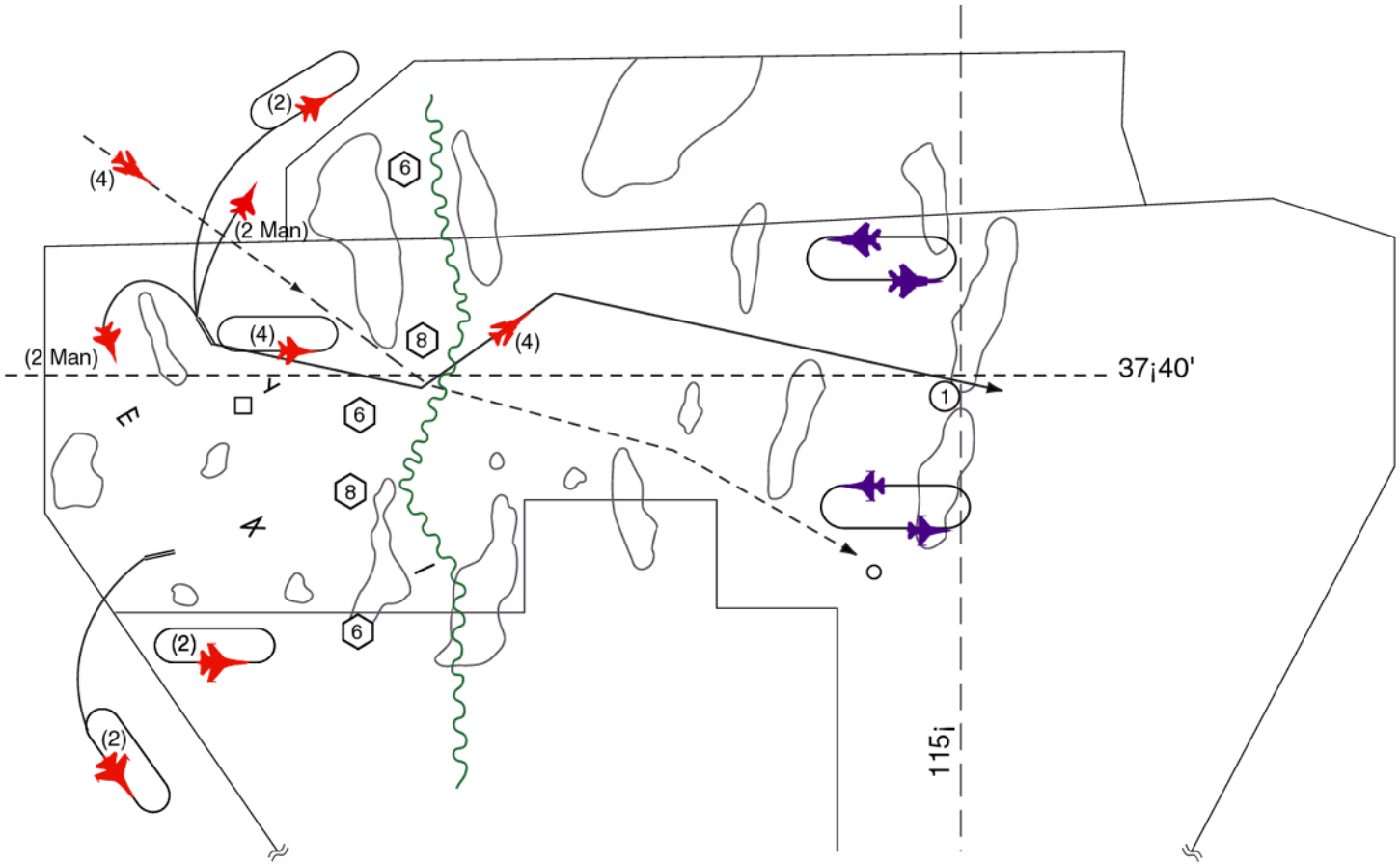
4-ship cap of Mig-29 south of Tonopah
2x 2-ship caps of Mig-29 capping south of Tolicha
2x Hind aircraft operating between Tonopah and Helen airfields are running resupply flights to two points along the FEBA: 03752N 11620W and 03730N 11620W.

Routes:

4x F-16CJ (Shooter 41) push from Steerpoint 1 . . . splits into two elements
- 2x F-16 CJ (Shooter 41) 1, 5, target Amstel
- 2x F-16 CJ (Shooter 43) 1, 3, 9 target Stroh's (set up between Strohs and Lonestar)

4x F-16C (Snake 11) 1, 3, 9, Target: Helen – egress North and East to Steerpoint 9
4x F-16C (Viper 21) 1, 5, 7, 10, Target: Storage Depot – egress South to Steerpoint 9
4x F-15 (Cylon 51) Push from Steerpoint 2 then as directed by mission commander

DCA Shields Up



INITIAL PICTURE
4 x MiG-29 Ñ Center CAP
2 x Su-27 Ñ South CAP
4 x F-15 proceeding North DCA CAP
4 x F-16 South DCA CAP

SCENARIO INPUTS
:04 Ñ VIPER relieves SNAKE in South DCA CAP
:04 Ñ 2 x MiG-29 (Man) takeoff Tonopah to North CAP
:09 Ñ 4 x MiG-23 strikers takeoff Tonopah
:09 Ñ 2 x MiG-29 (Center CAP) maneuver
:11 Ñ 2 x MiG-29 (Center CAP) maneuver
:18 Ñ 2 x MiG-29 (Man) attack
:23 Ñ 2 x Su-27 (South CAP) attack/drag
:28 Ñ 2 x Su-27 takeoff Tolicha to Southern CAP
:30 Ñ 2 x MiG-29 takeoff Tonopah to North CAP
:34 Ñ 4 x MiG-23 strikers takeoff North AFLD
:36 Ñ 2 x MiG-29 (Man) takeoff Tonopah
:42 Ñ 2 x MiG-29 (North CAP) attack
:44 Ñ 2 x Su-27 (South CAP) attack

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Day 2 - Wednesday (PM)
DCA

Scenario: In an attempt to allow the hostile nation the opportunity to withdraw military forces and cease offensive operations, the coalition partners have agreed to postpone airstrikes in favor of a defensive posture.

Commander's Intent: I intend to conduct defensive operations in an effort to stop an enemy attack against our oil-producing ally. By transitioning to a defensive posture, I intend to allow the hostile nation the opportunity to take the deciding step toward a peaceful resolution or a resumption of coalition airstrikes.

Target and Target Significance: N/A

BDA: #1 and #2 are unlocated.

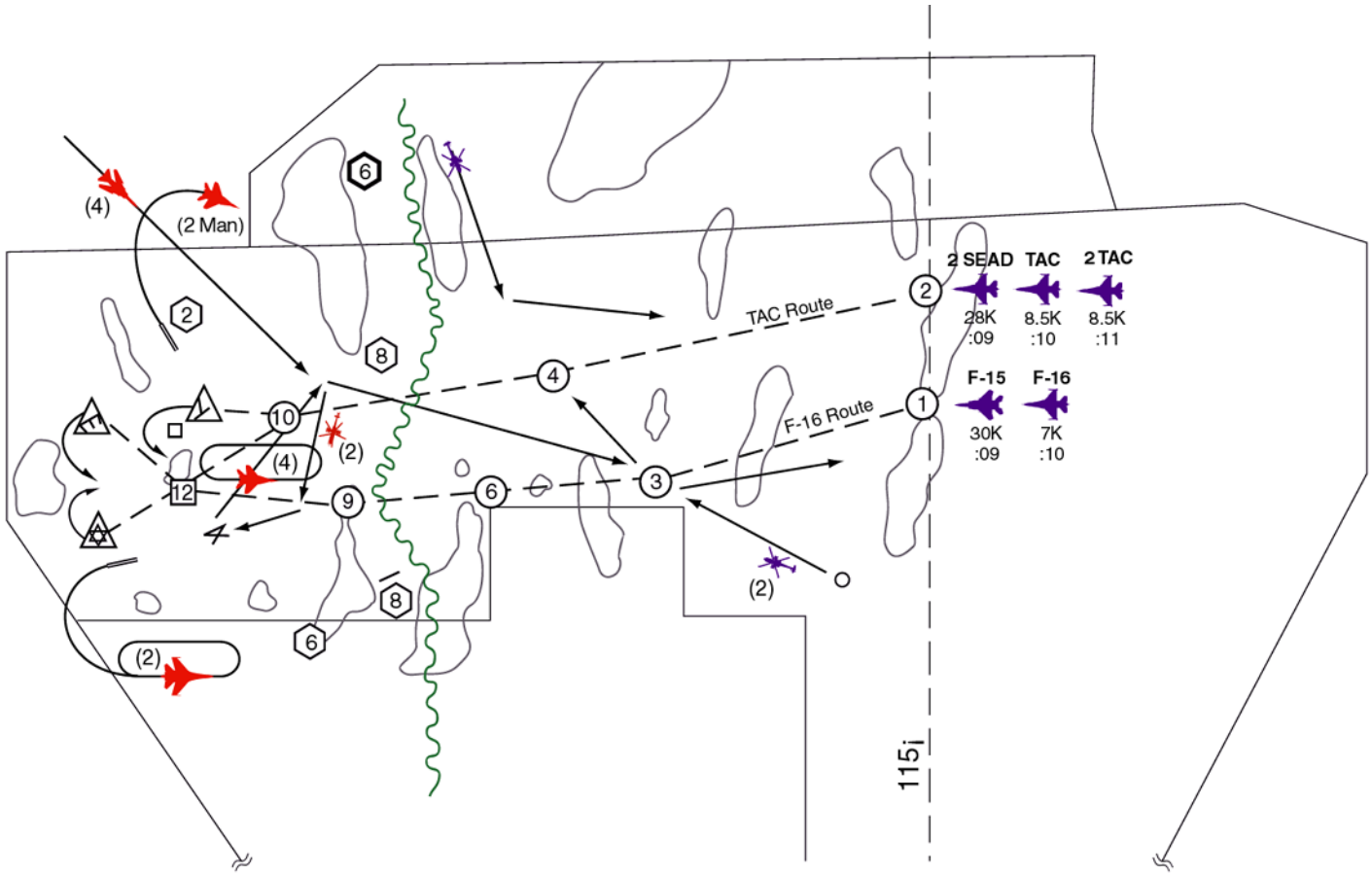
Operational Surface Threats: #5, #6, and #7 are new operational threats. SA-8 activity has been noted along the FEBA. The last known locations of the SA-8s were 3745N 11615W and 3730N 11615W.

Air Situation:

3-ship of Su-27 and 2-ship of Mig-29 out of Tolicha

Note: Lanes change for F-15/16 operating areas. F-15 are north of 3740N and F-16 are south of 3740N.

SEAD-C Shields Up



INITIAL PICTURE
4 x MiG-23 strikers takeoff North AFLD
2 x MiG-29 Ñ Center CAP
2 x Mi-24 Ñ Target Area

SCENARIO INPUTS
:02 Ñ 2 x MiG-29 (Man) takeoff Tonopah
:14 Ñ AH-64 takeoff Bear Paw
:14 Ñ 2 x MiG-29 (Center CAP) attack
:15 Ñ 2 x Su-27 takeoff Tolicha for South CAP
:16 Ñ AH-64 takeoff Alamo
:22 Ñ 2 x MiG-29 (Man) takeoff Tonopah

TARGETS
South SA-2 (F-16)
Korean Airfield (TAC)
Depot Airfield (2 TAC)

SEAD ATO

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76-10-03 SA-2//
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71-05-25 FUEL STORAGE//
MSNDAT/A1603/RR3A/DILLER31/2F16C/INT/-/2MK84/6MK82/36431//
AMPN/DEPOT AFLD
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R4809-02-01 RUNWAY INT//
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Day 3 - Thursday (AM)
SEAD-C

Scenario: Airstrikes continue with no change to the air situation. Ground troops have been observed massing along the central portion of the FEBA.

Commander's Intent: Due to the abundance of active SAMs operating in the area, I intend to suppress air defense assets to open up a corridor for coalition strike aircraft. I also intend to deny the use of both Korea Airfield and Depot Airfield, as the options for the hostile nation are narrowing for forward deploying enemy aircraft.

Target and Target Significance: Strikers will bomb the SA-2 site to support the SEAD objective. Korean Airfield runway and fuel storage, and the Depot Airfield runway intersection and parking ramp will be targeted to render them unusable for future forward deployment of enemy assets.

BDA: Neither threats #1 nor #6 surface threats were destroyed by SEAD assets on Wednesday afternoon.

Operational Surface Threats: #1, #3, #6, and #7 are operational. 2x SA-8s are operational along the FEBA. The last known locations of the SA-8 were 3745N 11615W and 3715N 11615W.

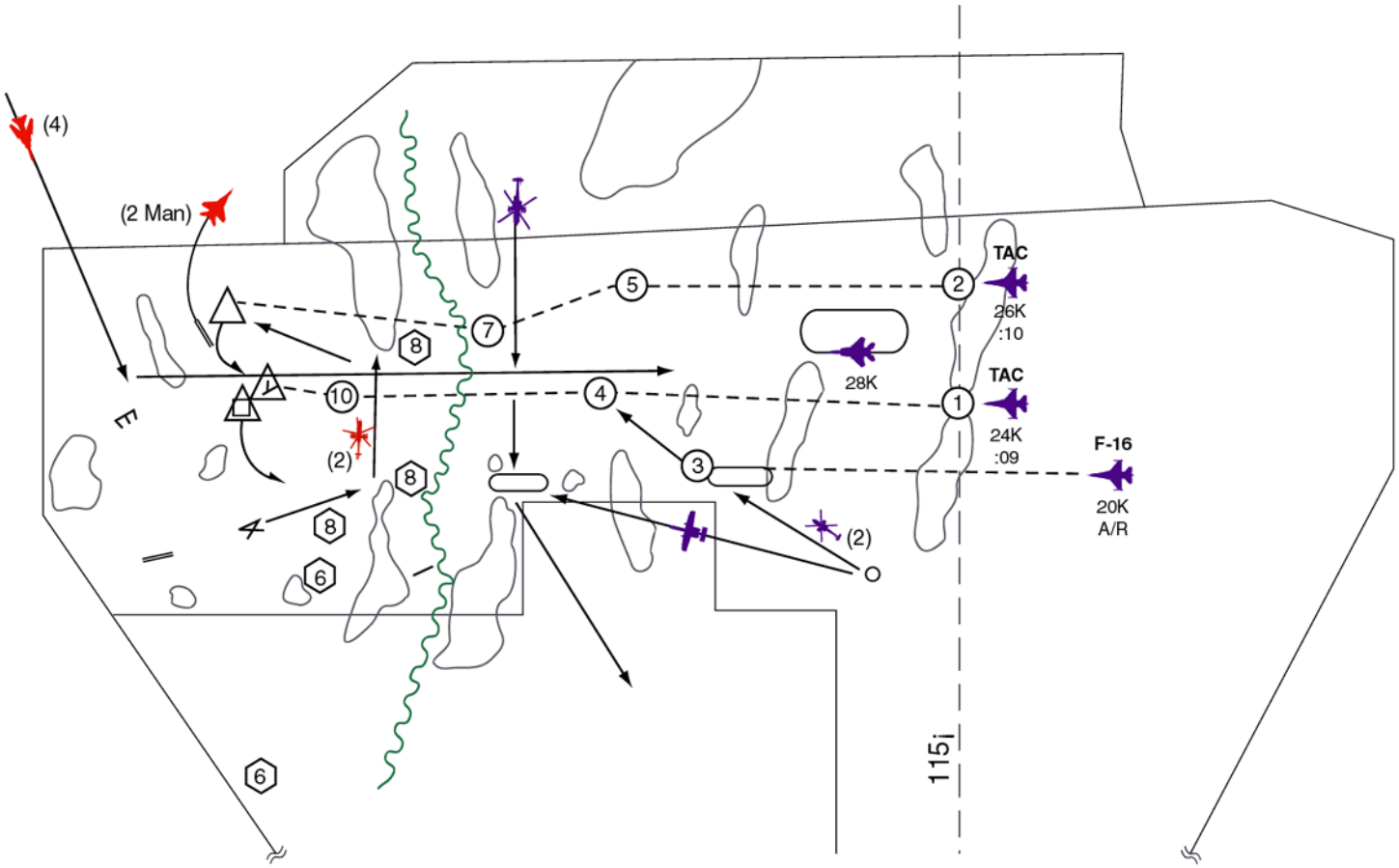
Air Situation:

2x Su-27 capping south of Tolicha
2x Mig-29 capping along 3730 between Helen and Depot Airfield
Hinds operating in the vicinity of the FEBA, flying a similar profile as yesterday.

Routes:

4x F-16CJ (Shooter 41) 2, 4, 5, target Amstel
4x F-16C (Viper 11) 1, 3, 9, 12, Target: Lonestar – egress North to Steerpoint 12 then 9
4x F-16C (Snake 21) 2, 4, 10, . . . then break into two elements
(Snake 21) 2, 4, 10, 12, Target: Korean Airfield – egress South to Steerpoint 12 then 9
(Snake 23) 2, 4, 10, Target: Depot Airfield – egress South to 9
4x F-15 (Cylon 51) Push from Steerpoint 1 then as directed by mission commander

CAS Shields Up



INITIAL PICTURE
2 x Mi-24 Ñ Target Area
A-10 Ñ Enroute contact point

SCENARIO INPUTS
:05 Ñ 2 x MiG-29 (Man) takeoff Tonopah
:07 Ñ AH-64 takeoff Bear Paw
:10 Ñ 4 x MiG-23 strikers takeoff North AFLD
:12 Ñ 2 x AH-64 takeoff Alamo
:15 Ñ A-10 identifies unknown SA-8
:25 Ñ 2 x MiG-29 (Man) takeoff Tonopah
:28 Ñ T-72 Armored column appears South Kawich Valley

TARGETS
SA-8/Tanks (F-16)
North SA-2 (4 TAC)
Storage Depot (2 TAC)
Depot Airfield (2 TAC)

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Day 3 - Thursday (PM)
CAS

Scenario: The massing of enemy Armor, Mechanized Infantry, and Attack Helicopters advancing towards and in the central portion of the FLOT/FEBA indicates the enemy has pushed over the FLOT/FEBA.

Commander's Intent: I intend to utilize CAS assets in the Kill Box and in the central area of the FLOT/FEBA to destroy the enemy's foothold and discourage any further enemy offensive attacks. US ground forces will remain in a defensive posture conducting Defensive Security Operations and will not engage enemy air attacks unless authorized to fire by the Fire Support Element (FSE) and Tactical Operations Command (TOC). US ground forces will defend themselves with Air Defense Artillery (ADA) and other measures as directed. Rules of engagement will be Visual Recognition of Enemy Aircraft before engaging.

Target and Target Significance: The storage depot support buildings, runway intersection, and parking ramp. SA-2 site and Kill box area, concentrating on enemy main battle tanks and enemy ADA.

BDA: NSTR

Operational Surface Threats: #3 and #8 are active. #1, #6, and #7 are unlocated. 3x SA-8s have been active along the FEBA. The last known locations of the SA-8s were 3745N 11615W, 3730N 11615W, and 3715N 11615W.

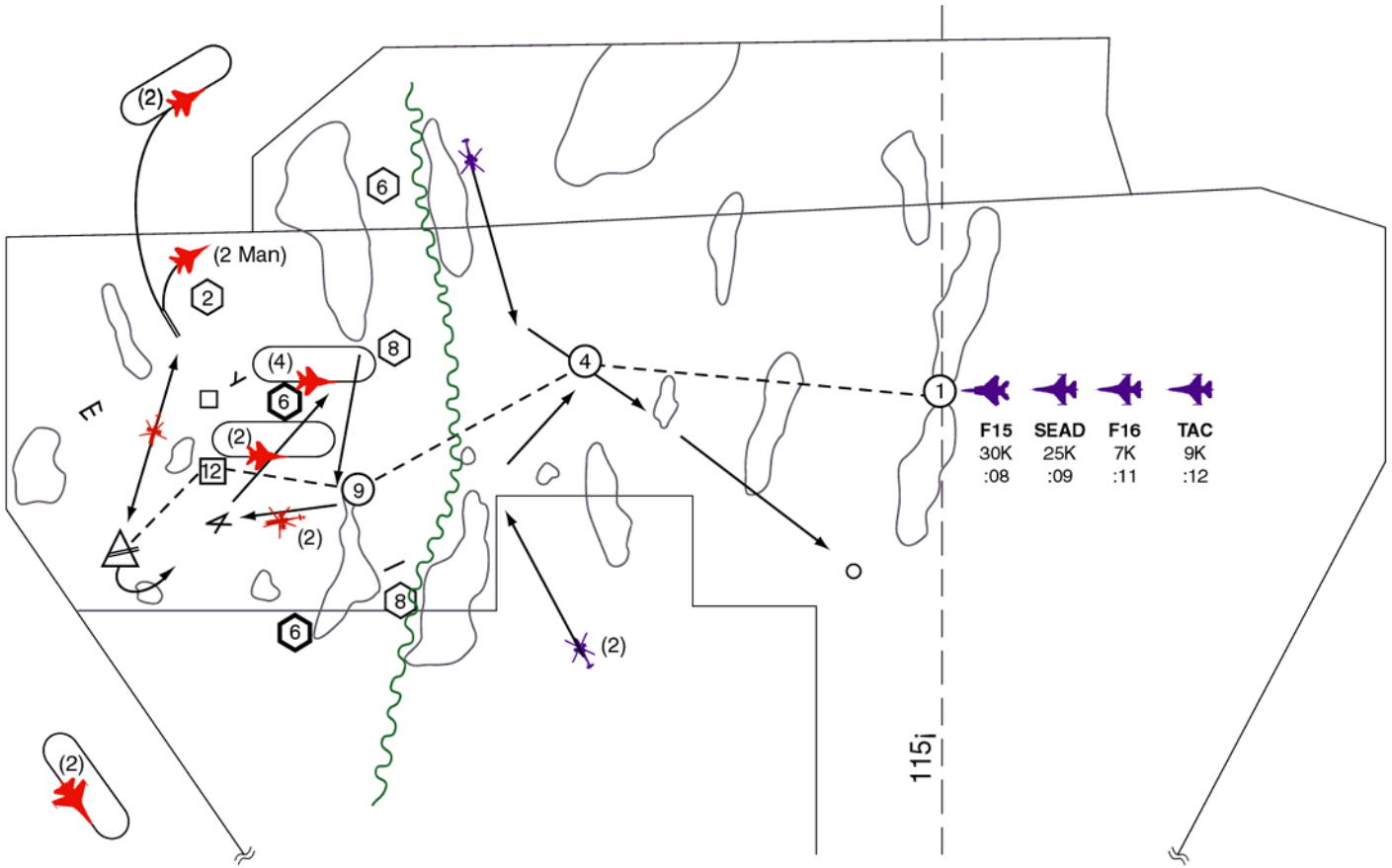
Air Situation:

2x Hind have been operating in the vicinity of the FEBA
Some Flogger activity has been noted at Tonopah Airfield

Routes:

4x F-16CJ (Snake 11) 1, 4, 10, Target: Depot Airfield – egress South
4x F-16C (Diller 21) 2, 5, 7, Target: Amstel – egress South
4x F-16C (Viper 31)
    Contact Point: Steerpoint 1
    Initial Point: Steerpoint 3
1x A-10 (Hog 01) will be on station capping southwest of Steerpoint 3
4x F-15 (Cylon 51) pushing from Steerpoint 2

SAT 2 Shields Up



INITIAL PICTURE
4 x MiG-29 Ñ North Center CAP
2 x MiG-29 Ñ Center CAP
2 x Su-27 Ñ South CAP
2 x Mi-24 Ñ Target Area

SCENARIO INPUTS
:05 Ñ 2 x MiG-29 (Man) takeoff Tonopah
:08 Ñ 2 x AH-64 takeoff Box
:11 Ñ Mi-24 takeoff Tonopah
:12 Ñ 2 x MiG-29 (North Center CAP) attack
:14 Ñ AH-64 takeoff Bear Paw
:15 Ñ 2 x MiG-29 (North Center CAP) attack
:17 Ñ 2 x MiG-29 takeoff Tonopah to North CAP
:20 Ñ 2 x MiG-29 (Man) takeoff Tonopah

TARGETS
Tolicha Airfield

TOTs
F-16 :22
TAC :23:30

SAT 2 ATO

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Day 4 – Friday
Post-Test

Note: Some participants will be flying SAT 1 first and some will be flying SAT 2 first as the post-test. Those personnel who flew SAT 1 for the pre-test will fly SAT 2 for the post-test and vice versa. The following information will display when there are differences between SAT 1 and SAT 2 for the post-test scenario.

Post-test Scenario (either SAT 1 or SAT 2): Given the tenacity of the enemy forces, the president of the hostile nation has decided to provide a last-ditch effort in repairing runways and attempting to launch aircraft out of Tolicha airfield.

Commander's Intent: My intent is to deny the use of Tolicha airfield by fourth-generation aircraft, specifically Flanker and Fulcrum, that are currently based out of Tolicha.

Target and Target Significance: Tolicha Airfield communications tower, pump house, and runway are to be targeted to deny Flanker and Fulcrum aircraft from utilizing support facilities and scrambling during coalition airstrikes.

BDA: #1 has not been destroyed and remains active.

Operational Surface Threats (SAT 2): #1, #5, #6, and #8 are operational. 2x SA-8s are operational along the FEBA.

Air Situation (SAT 2):

2x Mig-29 are capping out of Tonopah
4-ship and a 2-ship of Mig-29 are capping out of Tolicha
2x Hind are operating in the vicinity of the FEBA and 1x Hind is flying a route to/from Tonopah and Tolicha, moving aircraft parts.

Routes (SAT 2):

4x F-16CJ (Shooter 41) push from Steerpoint 1, 4 . . . splits into two elements
- 2x F-16 CJ (Shooter 41) 1, 4, 9, Target threats between Pils and Strohs
- 2x F-16 CJ (Shooter 43) 1, 4, Target threats between Amstel and Miller

9x F-16C (Snake 21 and Viper 11) 1, 4, 9, 12, Target: DMPIs on Tolicha Airfield – egress South to Steerpoint 9
4x F-15 (Cylon 51) Push from Steerpoint 2 then as directed by mission commander

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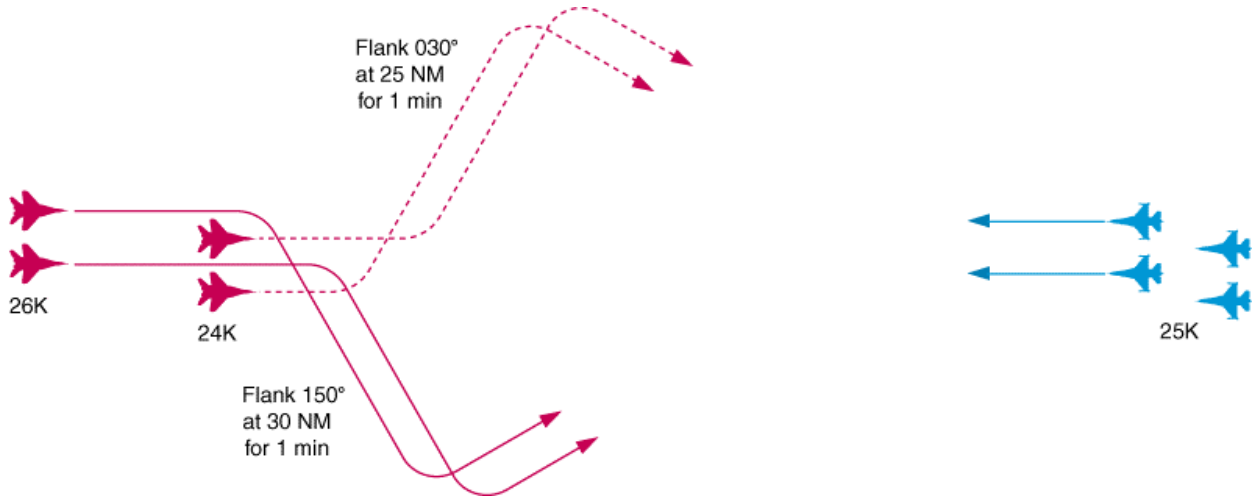
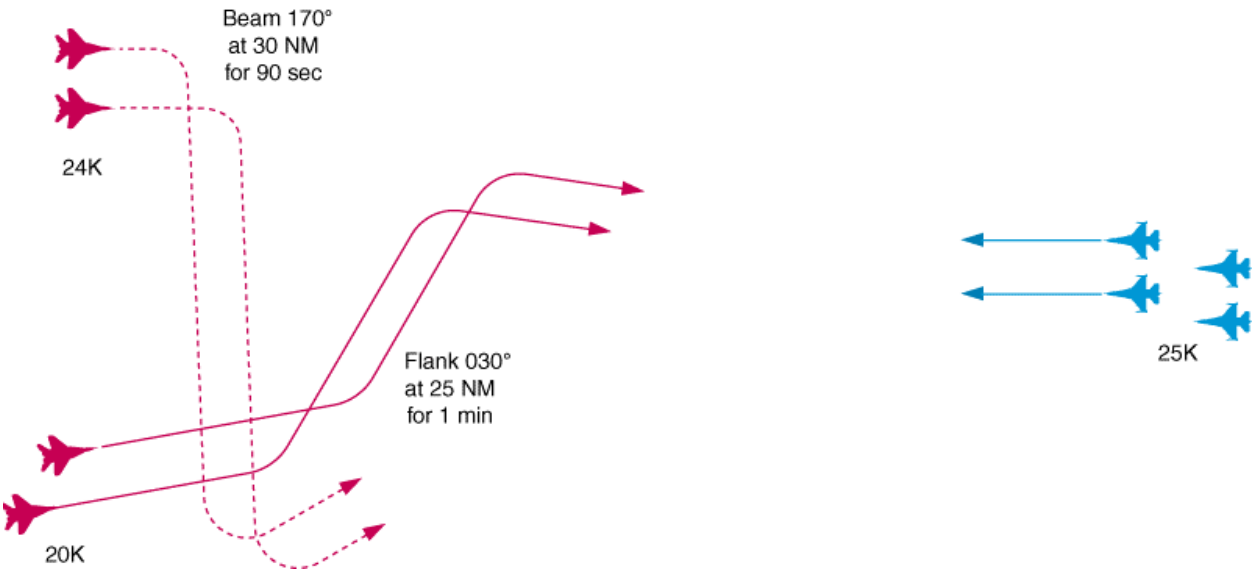
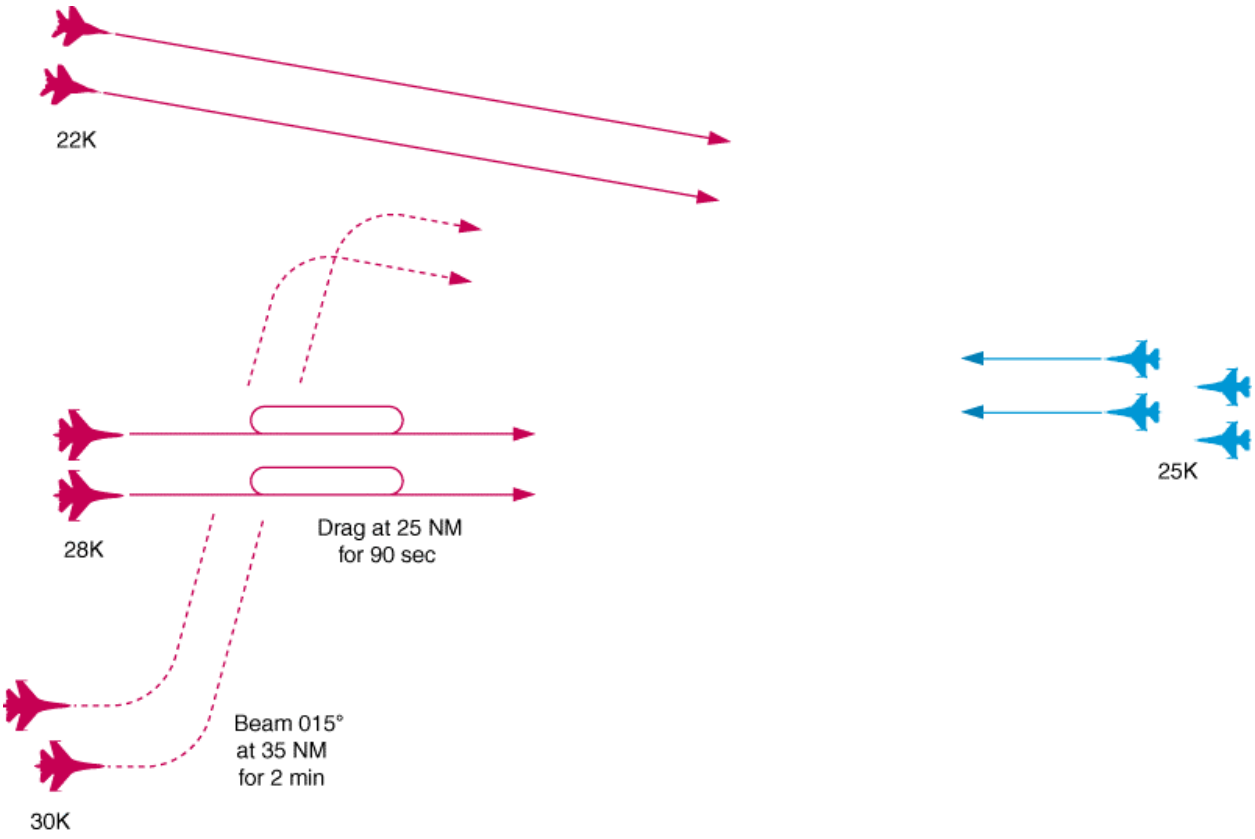
APPENDIX B

F-16 Air-to-Air Scenarios

This appendix contains depictions of the air-to-air scenarios conducted by F-16 teams at AFRL/HEA after completion of RoadRunner '98 missions.



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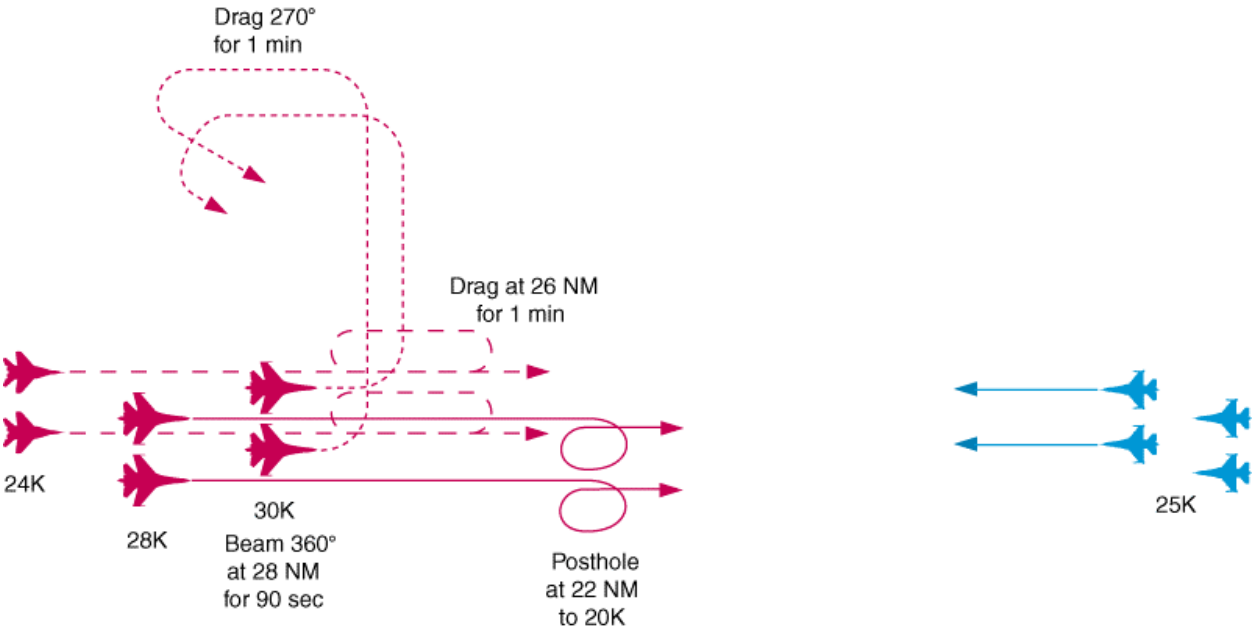
for 2 min
30K


Drag 270°
for 1 min
Drag at 26 NM
for 1 min
24K
28K
30K
Beam 360°
at 28 NM
for 90 sec
Posthole
at 22 NM
to 20K
25K

APPENDIX C

Analysis of AWACS Performance Ratings

Measurement of AWACS Team Performance in Distributed Mission Scenarios

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Abstract

Distributed Mission Training (DMT) enables participants to perform within a virtual battlespace created through networking of several high-fidelity simulations. In a recent exercise, RoadRunner '98, several agencies interacted to create several battlespace missions in which "friendly" fighter aircraft and command and control crewmembers participated as trainees, while supporting roles and enemy forces were either played by operational personnel (virtual players) or created by intelligent agent technology (constructed forces). Thus, trainees participated in complex demanding war scenarios without the usual constraints of cost, safety, and security normally associated with live-fire training. RoadRunner '98 was sponsored by the Air Force Modeling and Simulation Office (USAF/XOC) with the Air Force Research Laboratory, Human Effectiveness Directorate's Warfighter Training Research Division (AFRL/HEA) serving as program managers and the Theater Command and Control Simulation Facility (TACCSF) as systems integrators. Extensive support was received from the Training Office at Air Combat Command's Deputy for Operations (ACC/DOT), the Air Force Information Warfare Center's Advanced Combat Simulations Division (AFIWC/SAM), the Airborne Warning and Control Systems (AWACS) training office at the 522nd Air Control Wing, the 107th Air Control Squadron (ACS) of the Iowa Air National Guard (IANG), and the Naval Air Warfare Center's Training Systems Division (NAWC-TSD). The warfighters who participated in RoadRunner '98 were operational pilots, Weapons Directors (WDs), and Air Surveillance Technicians (ASTs) from the 522nd ACW, Tinker AFB, OK; the 27th Fighter Wing, Cannon AFB, NM; the 185th and 132nd Fighter Wings of the IANG; the 33rd Fighter Wing, Eglin AFB, FL; and the United States Air Forces in Europe (USAFE).

This paper describes the process by which C3 teamwork dimensions were identified, measures formulated, and the rating instrument refined. Measures of AWACS team performance were developed based on previously collected cognitive task analysis data and refined through the use of focal groups comprised of operational AWACS WDs or WD Instructors.

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1. Distributed Mission Training: Background

Distributed simulations have become an increasingly essential aspect of operational military training. As both training and defense budgets shrink, ways of reducing the number of flight hours and yet maintaining optimal levels of expeditionary force readiness are sought. Distributed Mission Training (DMT) is looked upon as a way that will allow warfighters to train in a manner consistent with Air Force Doctrine 60: *Train like you fight, fight like you train.* Previous constraints (e.g., safety, flying status, flying hours, aircraft and environmental factors) have hampered training efforts from following this philosophy to its fullest capacity. DMT addresses these constraints and allows the warfighters of our nation to perform crucial training missions with maximum proficiency and safety, at lower cost. General Fogleman, Chief of Staff Air Force, stated on 29 Jan 1996:

> *I am convinced modeling and simulation technologies available today will enable us to significantly change the way we train in the future. We are at a crossroads where simulator technology today will be critical in the success of our effective use of follow-on weapon systems …. We need to take a hard look at how this technology will change our training philosophy as well as how we develop future weapon systems.*

DMT is focused within a synthetic warfighting environment that grants a multitude of advantages for more accurate observation and assessment in areas that were previously difficult to research. Performance can be modeled within and across individuals, teams, squadrons, and complex functions. Linkages among diverse interdependent units can be identified and modeled to achieve greater efficiency. This intensive modeling of performance within a complex system enables a more precise assessment of the impact of interventions, such as training technology, cause and effect relationships, and changes in the distribution and display of information.

DMT offers flexibility that stretches worldwide by linking participants across network lines, allowing individual warfighter training to occur concurrently in simulators whose presentation of a commonly flown mission occurs in real-time. This capability supplements cockpit flight hours with a synthetic reproduction of a complete and complex warfighting environment that combines realistic scenarios with simulated operational systems. The focal point of this paper is the Airborne Warning and Control Systems (AWACS) segment of a Distributed Mission Training demonstration (RoadRunner '98). This exercise tied AWACS weapons directors from Tinker AFB, OK, F-16 aviators from AFRL, AZ, F-15 aviators out of Kirkland AFB, NM, and an A-10 aviator from AFRL, AZ together for one week of DMT training.

2. USAF AWACS Teams

All command and control teams share some common task and performance characteristics. These teams perform in highly interdependent roles, tracking and coordinating some type of tactical action, in a manner consistent with overall strategic goals and procedures, for a defined sector of air and/or land space over a sustained period of time.

The AWACS team serves within this team definition to augment the need for airborne surveillance and command, control, and communications functions for tactical and air defense forces. This provides the means to detect, identify, track, and intercept airborne threats. The aircraft's god's-eye capability offers an altitude-independent 360° view of more than 200 miles over both land and water. There are five mission crew categories related to the function of the AWACS crew: the Mission Crew Commander (MCC), Senior Director (SD), Weapons Director (WD), Air Surveillance Officer (ASO), and Air Surveillance Technician (AST). AWACS teams typically work in teams of two to four crewmembers as part of the airborne command and control group located within E-3 Sentry aircraft.

The RoadRunner '98 exercise focused primarily on the integration of multiple warfighter-in-the-loop training simulators, combining them with synthetic forces to form a virtual battlespace to conduct several assorted combat-oriented, tactical training exercises. The overall goal of this effort was to compare initial team performance with subsequent performance after participation, and give the participants the opportunity to critique both the systems and the concept of training (Parton, 1998). Each scenario was based on intelligence briefings and air tasking order (ATO), and each fighter and AWACS team planned, coordinated, and briefed their mission. The combined teams flew the mission in their respective simulators with a trusted agent monitoring and evaluating their performances. The teams and instructors participated in an after-action review aided by a mission playback system that assisted during the debriefing process. Each team participated in seven separate missions over the course of one week.

3. Development of Team Observer Form

The AWACS crew coordinates communications received from a number of sources, such as other WDs, the SD, air surveillance technicians (ASTs), electronic combat officers (ECOs), intelligence operations, base operations, and friendly pilots. To accomplish this, they must exchange, interpret and effectively weight information and optimize resource allocation decisions across team members, over time, and under stress and fatigue. These decisions regard shared resources, such as surface-to-air missile sites and various combat, reconnaissance, refueling, and search and rescue aircraft. Relevant information must be distributed to appropriate personnel and updated over time, in dynamic conditions which may require shift changes in personnel. Information is often verbal, and may be missing, degraded, passed along from unfamiliar sources, or misinterpreted by others. In addition, information is often communicated/interpreted by individuals with only partially overlapping awareness of the battlespace. For the RoadRunner '98 study, assessment of AWACS team of performance was based on SME ratings of several dimensions of AWACS team performance. These dimensions were generated based on cognitive task analyses, followed with focus groups comprised of experienced AWACS instructors. These focus groups served to refine the rating form, and included the SMEs who actually participated as RoadRunner '98 trusted agents/evaluators.

Cognitive Task Analyses

Assessment of individual and team performance in realistic combat environments requires (a) the capability to produce complex and dynamic scenarios, (b) identification of constructs that represent important individual and team skills, and (c) identification and/or development of construct measures. In addition, each scenario must have identified quantitative criteria of

mission success. Cognitive task analyses informed and influenced the development of scenario characteristics and the identification of primary performance constructs and measures.

Several cognitive task analyses have been performed on AWACS operational personnel. First, analyses have been performed with regard to AWACS individual tasks, with a primary focus on display enhancements (Klinger et al., 1993). In addition, Fahey and associates (Fahey et al., in review) investigated the AWACS task domain with a special focus on AWACS team tasks, utilizing cognitive task analysis and critical incident techniques for data elicitation. Their report provides a comprehensive description of the AWACS task, and the general finding that critical incident technique was quite useful for the description of AWACS teamwork.

In addition, a follow-up analysis of AWACS tasks, with a primary focus on team functions has been articulated and initiated (MacMillan et al., 1998). This was a preliminary investigation to test a team-based approach to cognitive task analysis. Results were very informative, supporting frameworks and constructs within an information-requirements approach to task descriptions.

4. Articulation of AWACS Teamwork

One core dimension that characterizes teams in general is the type and degree of interdependence among team members (Saavedra, et al., 1993; Salas, et al., 1992). Teams are distinguished from groups in general by a common purpose or goal, performed by interdependent team members (Salas, et al., 1992). From this definition we derived a core definition of teamwork: *The fundamental function of teamwork is the effective managing of interdependencies to accomplish a team goal.* From this core definition we identified six dimensions of team interdependence (Elliott & Schiflett, in review).

Discussion with focal groups comprised of AWACS subject-matter experts led to refinement of our preliminary team task taxonomy, as applied to AWACS team training and performance evaluation. Prior to the RoadRunner '98 exercise, we interviewed 38 expert AWACS weapons directors. These groups reviewed the proposed scenarios and assisted in the evaluation and refinement of an instructor/observer rating form (see Appendix). Review of the initial taxonomy, which was generated to classify teams in general, led to the identification of four teamwork functions which are specific to AWACS teamwork: (a) mission planning, (b) communication content/timing, (c) adherence to communication protocol, and (d) supporting behavior.

4.1 *Mission planning: formulation of "contracts"*

AWACS performance can be divided into three phases: premission planning, task execution, and debriefing (discussion after task execution). Mission planning affects AWACS teamwork by establishing roles, responsibilities, and contingency plans. As discussed by Fahey et al. (1998) and Macmillan et al. (1998) AWACS weapons directors explicate roles, responsibilities, and strategies to manage team member interdependencies through the establishment of "contracts." These contracts are made among AWACS team members (internal contracts), and to the "external" team (i.e., pilots of friendly assets).

4.2 *Communication: adherence to protocol*

AWACS weapons director tasks are based predominately on the exchange of verbal information. Communications are heavily standardized in terms of content (jargon) and process. This aspect of communication effectiveness refers to the degree to which individuals follow guidelines for communication exchange. In addition to proper jargon and syntax, communications must be clear, concise, and correct.

4.3 *Communication to support situation awareness*

Communications may be clear, concise, correct, and delivered according to proper protocol, and still be superfluous. The maintenance of situation awareness also requires that pertinent information be exchanged to the right person, at the right time. In such a communication-rich environment, too much communication can impede performance, when unnecessary information "steps over" other, more urgent communication. Indeed, part of the proper timing of AWACS communications to pilots involves knowledge of when to keep quiet.

4.4 *Supporting behavior*

While it would seem apparent that this aspect is most clearly representative of teamwork, the conceptualization of supporting behavior among AWACS weapons directors was more difficult to validate through subject-matter experts. While there was no doubt that AWACS teammembers do support each other, the argument was made that most of the support is in the form of communication exchange. AWACS teammembers support each other primarily through updates and reminders of salient information. At the same time, they can also transfer resources (responsibilities) and confer on decisions/actions, therefore, it was decided to keep this construct as an independent aspect of AWACS teamwork.

5. Rating Instrument

Once the dimensions of AWACS teamwork performance were refined by the SME focus groups, the rating instrument was tailored to capture these dimensions across three phases of performance: (a) premission briefing, (b) mission performance, and (c) mission debriefing. Ratings were based on a 4-point scale, using traditional rating assessment categories. The rating categories used are based on the same categories of performance used in AWACS WD training:

AWACS Team Observer Form
Rating and Definition of Performance Criteria

1. No Ability or Knowledge**. Task Failure**
2. Lacks Proficiency. **(Coordination, Communication, Cohesion)**
3. Uncorrected errors**. Degraded Mission Outcome or Endangered Friendly Forces**
4. Limited Proficiency**. Recognizes and corrects errors with team recovery. Mission Degraded**
5. Proficient**. No mission impacting errors. Team reacts correctly in current situations**
6. Highly Proficient**. Prevents errors. Team anticipates future situations. Plans ahead.**

NA = Not Applicable NO = Not Observed NP = Not Performed

Table 1: Rating Scale for Dimensions of Performance

WDs were rated on the following during the Phase I portion of their performance evaluation:

(a) Development of mission aids,
(b) Formulation of contracts internal to the AWACS team,
(c) Formulation of contracts external to the AWACS team, and
(d) Prebrief of pilots.

These aspects were identified during the subject-matter expert focal interviews as critical to successful premission planning and team performance. *The development of mission aids* included the generation, refinement, and review of the communications worksheet (which specifies who talks to whom on which channel), the fighter flow sheet, the chart, and the fact sheet, all of which describes and/or specifies procedures to enhance awareness and coordination. *Formulation of internal contracts* refers to the agreements made among the WDs as to their roles and responsibilities. Communication tasks and console assignments are set, specific mission objectives are discussed, and functional responsibilities and contingency plans are specified and assigned. *Formulation of external contracts* refers to the procedures executed between the WDs and others (pilots) with regard to roles and responsibilities, such as those regarding objectives, strategies, and communications. These contracts are then discussed within the briefing session (*Pre-brief Pilots)* by the lead WD with the lead pilot, along with issues such as the rules of engagement (ROE) and Air Tasking Order (ATO) compliance.

Phase II performance (during mission execution) was assessed by ratings regarding (a) communication in accordance with 3-1 and Unit Standards, (b) communications in support of situation awareness and the "big picture", and (c) mission execution. Communications are assessed in terms of adherence to established protocol, which strives to maximize aspects of clarity, brevity, and accuracy—communications that are clear, concise, and correct. This includes communications among WDs and also their communications to others (rated separately). In addition, communications are also rated with regard to relevance and timeliness—is the information what was needed to maintain team situation awareness—was the right information "pushed" to the right person at the right time? Mission execution was assessed through consideration of ATO execution, contract execution (formulated during premission briefing), and adaptive replanning (flexibility, problem-solving, contingency generation as needed).

Phase III (mission debriefing) performance was assessed through ratings of (a) reconstruction of the engagement, (b) evaluation of team objectives, (c) review of equipment issues, (d) review of team mission execution, and (e) review of information exchange. Reconstruction of the engagement was assessed through consideration of the process of reviewing the recordings and the identification of conflicts and/or problems. Objectives were reviewed in light of mission support and execution of contracts. Equipment issues included communication, console assignments, and any failures/alibis. Team mission execution was assessed through consideration of priority objectives, training objectives, and any failures/alibis. Information exchange was considered with regard to internal and also external communications. Communications should have supported overall situation awareness, and lessons learned should be identified during the mission debriefing.

Each team was rated on various dimensions of performance across three phases of performance, for each mission. They were assessed for performance in Phase I (premission briefing), Phase II (mission execution), and Phase III (mission debriefing). Measures and variable names are as follows:

5.1 *Premission Briefing*

Development/Use of Mission Aids (MSNAID_1): Effective use of appropriate mission planning aids, such as communications worksheets, charts, fighter flow sheet, and fact sheet.

Negotiation of Contracts Internal to AWACS Team (ICONTR_1): Effective discussion and coordination of interdependencies among AWACS WDs and AST, with regard to communications, console setup, mission tasks (who is primary/assist; coordination with AST), and mission objectives.

Negotiation of Contracts External to AWACS Team (ECONTR_1): Effective discussion and coordination with pilots, with regard to communications, mission tasks, and objectives.

Pre-brief with Pilots (PREVI_1). Effective discussion and coordination with pilots, with regard to objectives, standards (Wing and Squadron), Air Tasking Order compliance, and Rules of Engagement.

Overall for Premission Briefing (PHASEI). Average of above. Measures.

5.2 *Mission Execution*

Communications in accordance with Standards, Internal to AWACS Teams (COMMI_2): Extent of compliance to standard communication protocols, regarding continuum of control, Land Unit Standards, C-3 (Clear, Concise, Correct), and use of correct call signs.

Communications in accordance with Standards, External to AWACS Teams (COMME_2): Extent of compliance to standard communication protocols, regarding continuum of control, Land Unit Standards, C-3 (Clear, Concise, Correct), and use of correct call signs.

Maintenance of Situational Awareness and Big Picture in Communications Internal to AWACS Team (SA_PI_2): Content and timing of communications (as opposed to process).

Maintenance of Situational Awareness and Big Picture in Communications External to AWACS Team (SA_PE_2): Content and timing of communications (as opposed to process).

Mission Execution internal to AWACS Team (MSNEXI_2): Performance with regard to execution of Air Tasking Order, Contract execution, and adaptive replanning (flexibility, problem solving, and contingency).

Mission Execution External to AWACS Team (MSNEXE_2): Performance with regard to execution of Air Tasking Order, Contract execution, and adaptive replanning (flexibility, problem solving, and contingency).

Overall mission execution (PHASEII): average of six measures above.

5.3 *Team Debrief*

Reconstruction of Engagement-Internal to AWACS Team (RECENG_3): Effectiveness of review of engagement through review of recording and identification/discussion of conflicts/problems.

Evaluation of Performance with regard to Objectives Internal to AWACS Team (EVALON_3): Effectiveness of review of performance with regard to mission support and contracts.

Equipment-Internal to AWACS Team (EQUIP_3): Effective identification and discussion of issues with regard to equipment, such as communication and checkout, console assignments and check-outs, and failures/alibis.

Discussion of Team Mission Execution External to AWACS Team (TMISEX_3). Identification and discussion of issues with regard to support of priority objectives, WD/AST training objectives, and failures/alibis.

Information Exchange Internal to AWACS Team (INFEXI_3). Effective discussion of information exchange among AWACS team members, with regard to maintenance of shared mental picture (situation awareness) and lessons learned.

Information Exchange External to AWACS Team (INFEXE_3). Effective discussion of information exchange among AWACS team members and others, with regard to maintenance of shared mental picture (situation awareness) and lessons learned.

Overall Mission Debriefing (PHASEIII). Average of six measures above.

Overall Mission Performance (OVERALL). Average of all measures.

6. Results

Descriptive Statistics: Average ratings across teams (3), scenarios (7), and raters (2 per team and scenario for Phase II). Results indicate variance in distribution in ratings, with utilization of the entire rating scale, for most measures.

Premission Planning:	N	Minimum	Maximum	Mean	Std. Deviation
MSNAID_1	25	2.00	4.00	3.0800	.4933
ICONTR_1	25	2.00	4.00	2.9600	.6758
ECONTR_1	24	1.50	4.00	2.8125	.6726
PREVI_1	24	1.00	4.00	2.8542	.6833
PHASE I	25	1.88	3.75	2.9200	.4703
Task Execution:					
COMMI_2	42	1.00	4.00	2.9881	.7690
COMME_2	42	1.00	4.00	2.7143	.7741
SA_PI_2	42	1.00	4.00	2.9524	.7949
SA_PE_2	42	1.00	4.00	2.6905	.8762
MSNEXI_2	42	1.00	4.00	3.0000	.7730
MSNEXE_2	41	1.00	4.00	2.6951	.9413
PHASE II	42	1.33	4.00	2.8421	.7301
Debrief:					
RECENG_3	24	2.00	4.00	3.1250	.6124
EVALON_3	24	2.00	4.00	3.0417	.7929
EQUIP_3	26	2.00	4.00	3.1154	.4961
TMISEX_3	24	1.00	4.00	3.0833	.8805
INFEXI_3	25	1.00	4.00	3.0400	.8406
INFEXE_3	24	1.00	4.00	2.9792	.8140
PHASE III	27	1.50	4.00	3.0562	.5970
OVERALL	22	1.94	3.69	2.8699	.4705
Valid N (listwise)	16				

6.1 *Differences in performance attributable to differences among raters*.

ANOVA analyses indicated no significant differences among raters with regard to any of the measures. In addition, regression analyses based on the consideration of trusted agents, teams, and scenarios indicate that the variance attributable to differences among trusted agents was not significant.

6.2 *Relative impact of three sources of variance (trusted agents, teams, and scenarios).*

There were three primary sources of variance: that attributable to raters (which should be minimized), to differences among teams (not of primary interest here), and to the training exercise itself (differences among the seven scenarios was predicted to demonstrate improvement over time). Multiple regression analyses were performed, first on the model composed of trusted agents, teams, and scenarios. This model predicted 73% of the total variance in ratings. In addition, the consideration of trusted agents did not add to the prediction of ratings, thus indicating reliability of measures with regard to raters. The analyses were then run using teams and scenarios as predictors, and the model still predicted 73% of the total variance in ratings.

Model Summary: Predictors: (Constant), SCENARIO, TEAM, TRUSTEDA

Dependent Variable: OVERALL

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.859	.738	.694	.2603

ANOVA		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3.429	3	1.143	16.867	.000
	Residual	1.220	18	6.776E-02		
	Total	4.648	21			

Coefficients

		Coef-B	S.Err	Beta	t	Sig.
1	(Constant)	2.591	.221	11.750		.000
	TRUSTEDA	-4.394E-02	.045	-.117	-.969	.345
	TEAM	-.170	.070	-.294	-2.436	.025
	SCENARIO	.177	.027	.792	6.557	.000

a Dependent Variable: OVERALL

These data indicate that participation in the training exercise had a significant effect on performance, across all teams, and for most measures of performance across the three phases of performance. Results are described in further detail for the effects due to differences among teams, and differences across scenarios.

6.3 *Differences in performance attributable to differences among teams.*

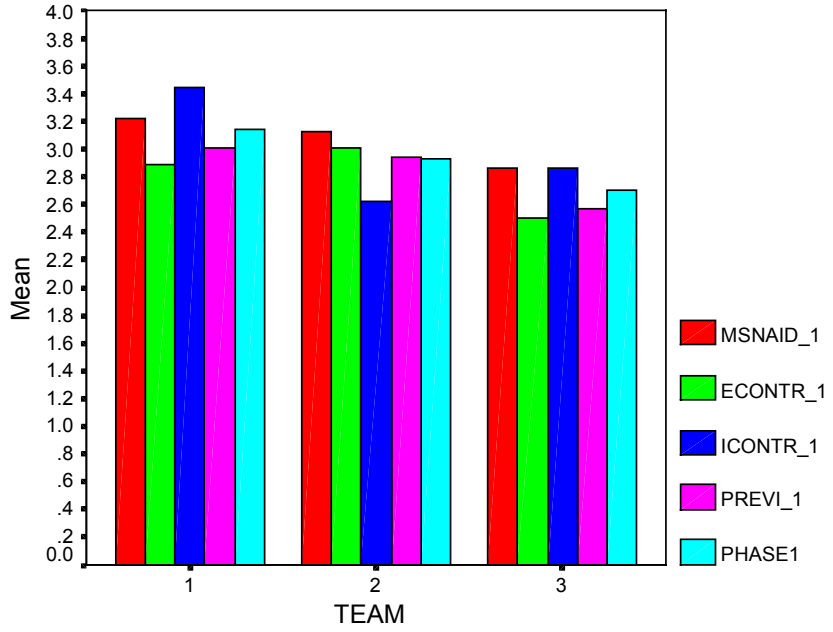
Data demonstrate the advantage in careful construction of performance constructs. The overall measure of performance was based on the mean of all measures; ANOVA results did not indicate

significant differences among teams. There were, however differences among teams for the measurement of one aspect (negotiation of contracts among team members) of performance during premission briefing, and for nearly all aspects of performance during mission execution. Teams did not differ significantly in performance during mission debriefing. An overall assessment of performance may be too generic to capture effects of a predictor variable.

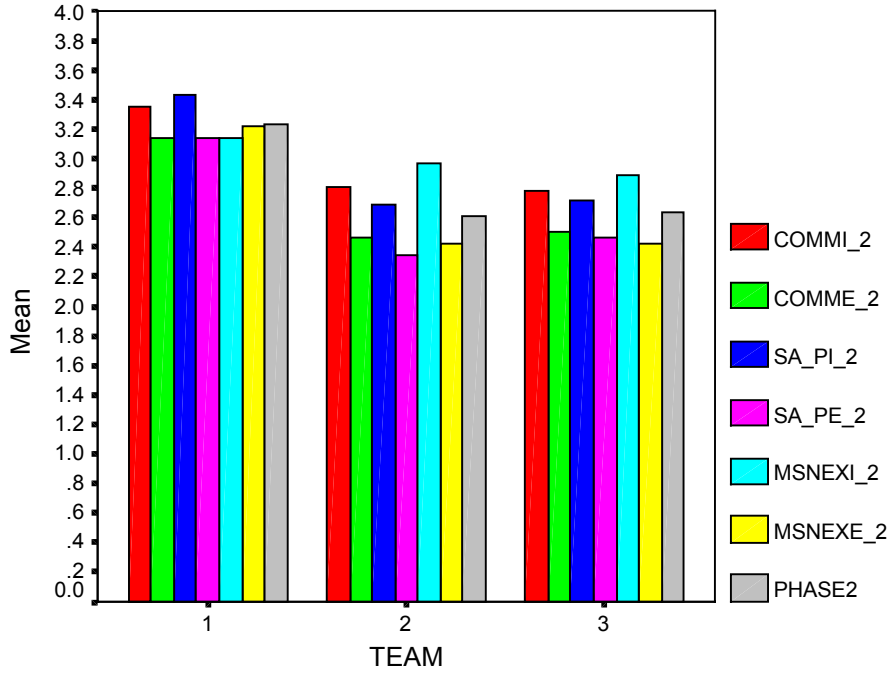
ANOVA: Significant Differences By Team, Between Groups

Variable	Sum of Squares	df	Mn Sq	F	Sig.
ICONTR_1	**3.363**	**2**	**1.681**	**4.869**	**.018****
MSNEXE_2	**5.730**	**2**	**2.865**	**3.665**	**.035****
SA_PE_2	**4.298**	**2**	**2.149**	**3.083**	**.057***
SA_PI_2	**4.762**	**2**	**2.381**	**4.392**	**.019****
COMME_2	**3.857**	**2**	**1.929**	**3.631**	**.036****
COMMI_2	**2.869**	**2**	**1.435**	**2.617**	**.086***
PHASE2	**3.298**	**2**	**1.649**	**3.466**	**.041****

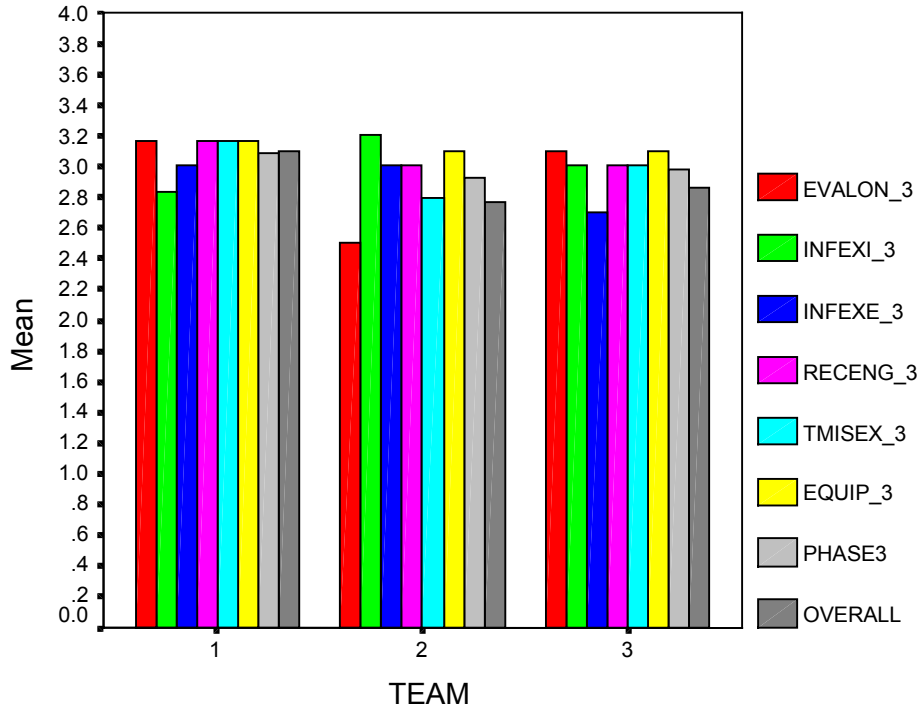
Performance Ratings for Phase I: By Team



Performance Ratings for Phase II: By Team

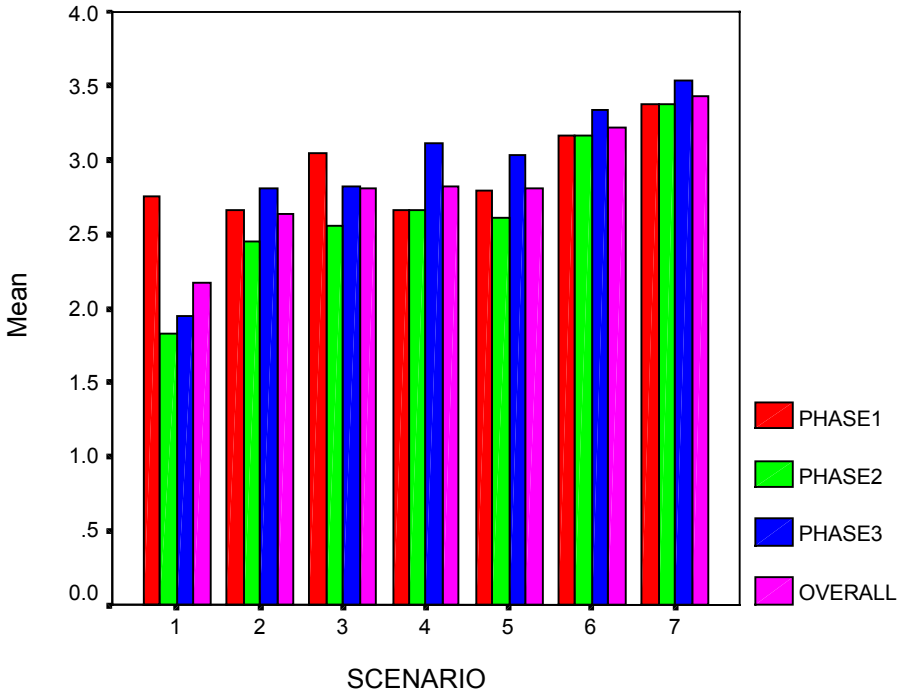


Performance Ratings for Phase III: By Team



6.4 *Differences attributable to scenarios and experience.*

Team performance differed significantly across scenarios for many of the measures (See Appendix for descriptives and ANOVA output). Differences in measures among scenarios would capture differences due to the scenario content, as scenarios differed in mission objective and content. They would also be due to experience over time. However, Scenario 1 and Scenario 7 are very similar in content, to better ascertain the effect of experience on performance. First we describe differences across all scenarios. The following graph describes overall results of instructor ratings of AWACS team performance, for each mission session, ordered over time.



The above graph provides a succinct glimpse of trends regarding the effect of simulation participation on performance, through differences in performance from Scenario 1 and Scenario 7, by phase. Here it can be seen that variance in performance across scenarios was more attributable to performance in Phases II and III: teams were lower in performance during Phase II and III during the first scenario, and demonstrated higher improvement in these phases. At the same time, performance during Phase I (premission briefing) also improved over time.

Overall results for each team for Scenario 1 (pretest) and Scenario 7 (post-test). Team A was the highest performing team for both pre-and post scores. Improvement for this team was consistent across the three phases. In comparison, Teams B and C performed less well from the start, and particularly less well in Phase II (mission performance) and Phase III (debriefing performance). Data indicate that training needs exist for the kind of training that distributed mission training provides: improvement in team premission briefing, team coordination and team debriefing. In addition, data demonstrate the effectiveness of participation in the training exercise for the improvement of performance across all phases of each mission.

7. Discussion

Results were consistent with expectations. Simulation-driven distributed mission training was expected to add value through the experience of complexity of team-on-team interdependencies. The immersion of individuals into teams within a global mission scenario should enhance their capability of managing these interdependencies during performance. Debriefing experience is particularly valuable to AWACS crew as they often do not get the advantage of debriefing with pilots after the mission; their mission usually extends beyond the time of performance of a particular combat aircraft. The value of this experience is indicated by the increased performance during debriefing of later mission scenarios. In addition, teams improved on most aspects of performance throughout mission planning and execution.

Data demonstrate the advantage of careful construction of performance constructs. The overall measure of performance was based on the mean of all measures; ANOVA results did not indicate significant differences among teams. There were, however differences among teams for the measurement of one aspect (negotiation of contracts among team members) of performance during premission briefing, and for nearly all aspects of performance during mission execution. Teams did not differ significantly in performance during mission debriefing. An overall assessment of performance may be too generic to capture effects of a predictor variable.

8. Summary

The following quote very aptly captures the essence of the RoadRunner '98 experience:

> *The RoadRunner '98 concept of operations and its execution was a valuable tool in development and evolution of Distributed Mission Training (DMT). This exercise demonstrated the ability to interface multiple virtual warfighters and synthetic forces to form a virtual battlespace that can be used to conduct realistic combat-oriented training. Our goal was to compare team performance before and after DMT training and to give the participants the opportunity to critique both the systems and this concept of training. The initial comments from the AWACS crews suggest that they found DMT to be a viable and productive training tool. The technology was proven capable of providing combat-oriented training at low cost, with fewer risks, while still maintaining the security constraints associated with aviation duties. RoadRunner '98 has shown the potential to provide improvements in pre-planning and mission execution with emphasis in shared training exercises to provide endless training opportunities to the 21st century aviator.*
>
> *Randy L. Parton, Major, USAF*
> *Chief, Modeling and Simulation*

The approach taken during the evolution of the rating scales enabled the collection of data that significantly adds to the understanding and research of team communications, interdependencies, and training.

Post-mission questionnaires provided comments, information, and guidance that have proves helpful in the creation of continued DMT missions and research.

Participants responded to:

How mission impacted learning and training:

- *A staged 4-day war would be very beneficial.*
- *Using voice/data recording capability helps us pinpoint errors and allows a thorough debrief, enhancing the learning experience.*

Whether exercise helped meet squadron training objectives:

- *Good intro to a Red Flag exercise.*
- *Great real war training, with inexperienced … benefiting most.*

Whether exercise has the potential of meeting squadron training objectives:

- *Work the bugs and this could be a simulated Red Flag.*
- *It will definitely increase amount of learning gained from SIM.*

Suggestions for improvements:

- *Tie SIMs together with a grand order of battle, Intel, and more complete mission planning.*
- *Allow full-crew participation.*
- *Anything that can go wrong on the jet needs to be able to go wrong here.*

In addition, participants commented on the number of "lessons learned" that occur when training involves so much training in one week, and believed the non-predictability of real pilots manning the aircraft, as opposed to sim drivers, added indescribably to the realism of the mission.

The ongoing development of distributed mission training will allow USAF to move into the next century as a cohesive, well trained warfighting unit. The technology and research providing the foundation for this capability will allow for a more efficient, cost-effective, and objective means of training that has only begun to make its impact on the military concept of warfighter readiness.

9. References

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