Development, Test and Evaluation of a Multiship Simulation System for Air Combat Training

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ABSTRACT

The Aircrew Training Research Division of Armstrong Laboratory at Williams AFB, AZ has developed a SIMNET Version 6.6.1 compatible network of dissimilar aircrew training devices. The multiship research and development system (MultiRAD) uses distributed micro-processor technology to integrate: an exercise control and videotaping system, two high fidelity F-15 and two lower fidelity F-16 cockpits, visual display systems, a ground controlled intercept (GCI) station, and a computer generated threat system. As part of systems integration and development, four one-week tests were conducted in which F-15 pilots and air weapons controllers participated in simulated air combat training exercises using the MultiRAD system. During these exercises, pilots and controllers flew simulated offensive and defensive counter-air missions against a force of up to six threat aircraft plus surface-to-air missiles. Participants then evaluated the utility of the MultiRAD system for air combat training. System components were modified after each of the four weekly tests based on the participants' evaluations. Systems development, integration, and modifications, based on pilot and controller evaluations, are discussed along with lessons learned.

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INTRODUCTION

The Advanced Research Project Agency (ARPA)/Army Simulation Network (SIMNET) program demonstrated that allowing combatants in simulators to interact with each other within a common gaming area greatly increased the value of simulator based training. Further, the SIMNET program demonstrated the feasibility of a network based on selective fidelity player stations using distributed microprocessor technology and an asynchronous communication protocol. Armstrong Laboratory's Aircrew Training Research Division evaluated the concept of networked simulator training for air-to-air combat in a series of advanced air combat exercises conducted at McDonnell Aircraft Company (Houck, Thomas, and Bell, 1989). Pilots in these exercises reported that the training received from networked simulators was superior to their current unit training for tasks which cannot be practiced in the actual aircraft due to cost, safety, and security restrictions. However, unlike SIMNET, the simulation facility at McDonnell Aircraft was designed for engineering development and uses very high fidelity cockpits and mainframe computer technology.

The multiship research and development program (MultiRAD) was initiated at the Aircrew Training Research Division in the spring of 1991 to create a SIMNET compatible system of networked simulators for air combat training. The initial objective of MultiRAD development was to integrate new and existing devices into a system which would provide high fidelity training for limited components of the F-15 air combat mission. The system would then be evaluated in a series of simulated air combat exercises known as the Training Requirements Utility Evaluation (TRUE). In the TRUE, teams of two F-15 pilots and an air weapons controller would either defend an air base against an attack or would escort a flight of F-16s attacking the air base. System performance and participant evaluations would then be used to identify the training opportunities provided by MultiRAD and to direct further MultiRAD development. In this paper, we will discuss the components in the MultiRAD system, the integrating network, a summary of the TRUE evaluation, and a discussion of lessons learned and opportunities for future development.

MULTISHIP RESEARCH AND DEVELOPMENT (MultiRAD) SYSTEM

The MultiRAD system consists of several independent systems connected via network interface units (NIUs) which convert each device's unique codes into a common communication protocol. The components used in the TRUE were: two F-15 cockpits, computer image generation and displays for the F-15s, two opposing forces cockpits, an air weapons controller station, a computer generated threat system, an exercise control and video recording station, and a separate video debriefing station (see Figure 1).

F-15 Cockpits

The two F-15C cockpits used were McDonnell Douglas Reconfigurable Cockpits (MDRCs). The MDRC incorporates high fidelity stick and throttle grips with a color CRT/touch screen depiction of the front panel (see Figure 2). The MDRC uses commercial, off-the-shelf, VME-based, microprocessors to perform all internal functions. Inside its single

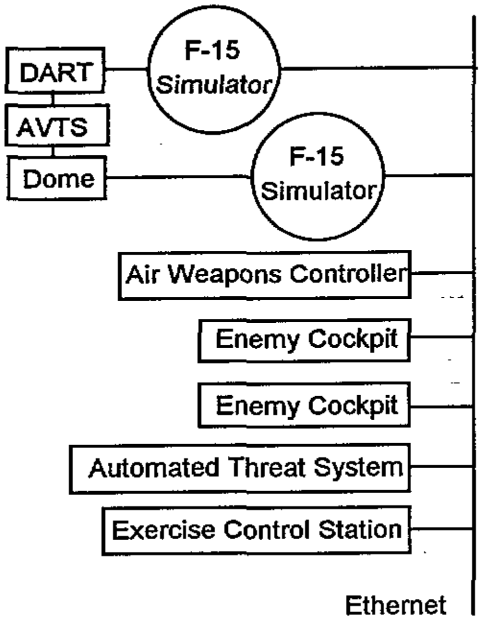

Figure 1. Multiship research and development (MultiRAD) network.

VME chassis, the MDRC has four Motorola 68030 single board computers, one Motorola quad-processor (88100) computer board, two computer image generator board sets, a sound board, and several digital to analog and analog to digital converters. The two image generators are used to provide the cockpit instruments and the head-up display (HUD). The sound board provides weapons cues and aircraft audio such as engine sounds and g-limit warnings.

Figure 2. McDonnell Douglas Reconfigurable Cockpit (MDRC) installed in Display for Advanced Research and Training (DART).

The MDRC has a high fidelity F-15 software suite that is derived directly from the McDonnell Douglas engineering simulators in St. Louis. The software includes an F-15 aerodynamics package, a full assortment of air-to-air weapons, a complete radar package, a radar warning receiver (RWR), a HUD, electronic counter measures (ECM), and electronic counter-counter measures capabilities (ECCM). The MDRC provides high fidelity simulation only for air combat functions; there are no rudder pedals or provisions for landing, refueling, or emergency procedures.

F-15 Visuals

Computer Image Generation Imagery was provided by the General Electric Advanced Visual Technology System (AVTS) which was the engineering prototype for the CompuScene 4. AVTS provides 8000 faces distributed among ten channels at 60 Hz.

Displays - One MDRC was installed in the McDonnell Douglas full field-of-view dome. This system consists of a 24' diameter dome with 360° horizontal by 190° vertical coverage. The display system incorporates six background projectors with a resolution of 4.3 arc-min/pixel and a 40°, head tracked area of interest (AOI). Resolution in the AOI was 2.4 arc-min/pixel. Only the AOI and the three forward channels were used during the TRUE resulting in an 210° horizontal by 100° background field-of-view. The AOI could be slewed throughout the dome. The other MDRC was installed in the Armstrong Laboratory display for advanced research and training (DART). The DART is a dome-like display system consisting of eight segments of a dodecahedron which surround the cockpit (Thomas, Reining, and Kelly, 1992). Each segment is a rear projection screen approximately 1 meter from the pilot's head (see Figure 2). During the TRUE, imagery was projected onto only six of the screens at a time as controlled by a head tracker. The DART's field-of-view during the TRUE was 300° horizontal by 200° vertical with resolution of 4.75 arc-min/pixel. Unlike the dome pilot, the DART pilot could not see to the rear of the aircraft.

Opposing Forces Cockpits

Two Armstrong Laboratory combat engagement trainers (CETs) were integrated into the network as opposing airborne interceptors. CETs are limited function F-16 trainers equipped with air-to-air radar, AIM-9 missiles, and radar warning receivers (Boyle and Edwards, 1992). For the TRUE, the F-16 aerodynamics simulation was replaced with aerodynamic and engine characteristics of an Su-27 interceptor.

Air Weapons Controller Station

The Simulated Command and Control Environment Networked Training System (SCCENTS) was developed by the Logistics Research Division of Armstrong Laboratory to provide the Air Force with a low-cost command and control workstation for research, development, and training. The system was designed to be integrated to networks such as SIMNET or Distributed Interactive Simulation (DIS). The SCCENTS has two display modes - an Airborne Warning and Control System (AWACS) or the 407L Ground Control Intercept (GCI) display. The AWACS display was used for the TRUE study because it provided more physical information about the battle to the controllers. The SCCENTS also has a digital database developed from Defense Mapping Agency data.

Computer Generated Threats

The F-15 and opposing forces cockpits, visual image generators, displays, and the controller station were existing systems which were adapted for network operation. The automated threat engagement system (ATES) was developed especially for the MultiRAD effort (Rogers, 1992). The ATES simulates ground and air threats plus friendly aircraft. Ground threats include: headquarters functions with early warning radar, directed and autonomous surface-to-air missile (SAM) batteries (SA-4, SA-6, and SA-8) with their radars, and ZSU-23 anti-aircraft artillery (AAA). ATES air threats used in the TRUE were Su-27 interceptors with radar and infrared guided missiles and MiG-27 attack fighters equipped with radar jammers. ATES also supplied four F-16 strikers used during offensive counter-air missions. While the ATES hardware was specifically developed for MultiRAD, the threat models and integrating software are "a blend of several programs from various government agencies and a commercial vendor," (Rogers, 1992, p.303).

Exercise Control

Multiship simulation exercises were directed from a central console which contained systems to set up, initiate, observe, videotape, and terminate sorties. Initial conditions and actions of automated opposing forces were preprogrammed in the ATES. Initial conditions for all manned players are programmed in the exercise control station. Monitors at the control station displayed: 1) an overhead view of the engagement, 2) each F-15's front panel including radar, radar warning, and armament control displays, and 3) one channel of out-the-window video (the AOI for the dome and the forward channel for the DART). The test director had intercom communication with each player station. Incorporated into the exercise control station was a computer controlled, video taping system which recorded the two F-15 front panels and the overhead view plus all radio communication. Computer control allowed synchronized start, stop, and playback of the three videotapes.

Debriefing station

After each simulator session, the two F-15 pilots and the air weapons controller would take the videotapes to an independent debriefing room which contained three computer controlled tape players and monitors. After brief instruction, participants were able to review their engagements and could stop, rewind, and replay segments of particular interest. Since the debriefing system was independent of the simulators, a second team could fly while the first was debriefing.

SYSTEM DEVELOPMENT AND INTEGRATION

Network Interface Units

The NIU provides a method of communicating between the host simulator and the MultiRAD network (SIMNET). The NIU and host communicate with one another according to a predefined *language* which is described in the system's Interface Control Document (ICD). The NIU uses ethernet as the physical medium to communicate both with the host computer and SIMNET although other mediums such as Fiber Distributed Data Interface (FDDI) and reflective memory are available for use. The NIU's primary functions include coordinate system conversion, Remote Vehicle Approximation (RVA), data filtering, and conversion of units of measure.

Armstrong Laboratory developed one NIU for each of its networked simulation systems. The NIU's hardware consists of two Motorola 68030 single board computers with transition modules, an enhanced ethernet interface board from CMC Corporation, a SIMVAD digital voice processing board, a SIMVAD voice communications adapter with a headset, a twelve-slot VME chassis, and a removable disk drive assembly. One computer board processed simulation data between the SIMNET network and the simulation host while the other board processed digital voice data between the host and the network. The CMC ethernet processor board was chosen for communications between the NIU and SIMNET because it was faster than the MVME712 transition module interface. The CMC boards also contained firmware to monitor ethernet statistics such as collisions and bad packets.

Communications Protocol and Extensions

SIMNET was developed by the Army and ARPA for tanks and slow moving air vehicles. Armstrong Laboratory implemented a subset of the SIMNET Protocol Data Units (PDUs) specific to air combat operations. Initially, the activate request and response, deactivate request and response, vehicle appearance, fire, and impact PDUs were implemented and tested. After all systems were able to communicate with each other and observe each other in the synthetic battlefield, the protocols were extended to include freeze, radar, and emitter PDUs. The MDRCs provided the most fidelity and were chosen to provide the testbed for implementing the protocol extensions. The MDRCs were first tested one on one, then integrated to the other devices on the network.

All SIMNET PDUs were modified to add a timestamp field. Additionally, fifteen extra result types were added to the impact PDU to enhance scoring capabilities. Originally, the SIMNET protocol only had four results for scoring: miss, ground impact, vehicle impact, and proximity impact. A freeze PDU was also implemented to allow the exercise control station to stop (freeze), and continue any mission.

The radar and emitter PDUs were designed to pass all the information needed about a specific radar or emitter over the network to other vehicles. The radar PDU includes radar system, radar mode, radar ID, sweep, power, and a list of illuminated targets. The emitter PDU includes the number of emitters, emitter class, mode, power, frequency, and sweep. Air-to-air tacan, IFF, jammer, and radio emitters were specifically implemented on the network. One issue that had to be addressed was the classified nature of the radars and emitters of the MDRCs. Should classified data be sent over the network or do all players have classified information about every other player on the network? Armstrong Laboratory implemented the PDUs such that individual packets were not classified but aggregates of packets may be classified.

Each system had different levels of computing ability. The MDRCs originally could only handle eight threat vehicles, eight missiles, and eight ECM bodies. After upgrading the system to Motorola 88100 processors, the system was increased to handle fifteen threats, eight network missiles, eight internal missiles, eight network ECM bodies, eight internal ECM bodies, and eight SAM/AAA sites. The CETs on the other hand could only handle six network vehicles. A priority routine was used to monitor the closest threats. Similar limitations existed in the visual systems where priority schemes were also implemented.

While integrating the MDRC to the network, a single vehicle update message was designed to transfer simulation information about all entities on the network. This single vehicle update message contained position, velocity, and state information including radars and emitters. However, ECM and missile entities do not need to pass information such as radars, emitters, and throttle position. A second, streamlined, vehicle appearance message was created for ECM and missiles to reduce the amount of traffic between the host and NIU.

Problems Encountered

Many unexpected problems arose during the integration of the systems for the TRUE. For example, the CETs and ATES were accepting any impact message containing their vehicle ID as a kill without looking at the result. Under certain circumstances, the MDRCs would kill vehicles when the gun trigger was depressed- even though the vehicle was 80 miles away. Ghost vehicles were also created on the network due to improper memory management. Still another memory management problem allowed vehicles to attain attributes of vehicles that were previously in that portion of memory. A CET might fly a jamming mission in one sortie; in the next sortie, whichever vehicle occupied the same memory space had the jammer flag set.

During the TRUE, networked vehicles jittered in the visual systems. Several reasons for jitter were identified. One portion of the jitter occurred when a vehicle exceeded the RVA dimensions. Jitter was also caused by the different frequency rates of the devices on an asynchronous network. Still another cause for jitter was simulator or NIU overloading. When a device could not send and receive packets at its predefined update rate, it would take large jumps in the visual systems. Finally, coordinate conversions and precision were found to be contributors to jitter. In the early stages of the TRUE, some vehicles were making large jumps in the visuals. The coordinate transformation algorithms in the NIUs were found to be incorrect. All systems were analyzed and modified to reduce the possibility of overloading. The scenarios were also analyzed to ensure devices did not overload due to network traffic. Additionally, the coordinate transformations were corrected. The resulting jitter was deemed acceptable to the program because it was minor. A smoothing algorithm could be used to further reduce the jitter but was not implemented due to system loading.

TEST AND EVALUATION

The objective of the TRUE was to evaluate the strengths and weaknesses of the MultiRAD system. The primary data for this evaluation were pilot comments from daily debriefings and questionnaires completed after each simulator session. These comments were used to improve the MultiRAD system after each week of the TRUE. Training effectiveness was evaluated by relating pilot and air weapons controller ratings of system utility to rated training effectiveness. These evaluations would be used to determine whether the training benefits seen in the McDonnell-Douglas Advanced Air Combat Training exercises could be obtained using the MultiRAD system.

Procedures

The TRUE consisted of four, one-week training exercises for teams of F-15 pilots and air weapons controllers. The TRUE exercises were conducted in Oct., Nov., and Dec. 92 and Jan. 93. Three or four teams participated each week, with a team consisting of a lead pilot, a wing pilot, and a controller. Each team flew offensive and defensive counter-air missions against a force of up to six aircraft plus surface threats. During each of seven simulator sessions, a team flew their mission three or four times with different tactics used on each setup. After each simulator session, teams reviewed videotapes of the engagements and completed an evaluation questionnaire. Participants were also asked for their evaluation of the MultiRAD system during daily meetings and during individual interviews.

Participants

Twenty-three, USAF, F-15 pilots and thirteen air weapons controllers participated in the TRUE exercises. Pilot experience levels ranged from 300 to 2500 total flying hours with a median of 1400 total hours and 675 F-15 hours.

RESULTS

During the four weeks of the TRUE, 78 hours of multiship simulator exercises were scheduled and 72 were completed; six hours (8%) were lost to major systems failures. Within the 72 hours, 267 multiship setups were conducted. Of these, 204 setups were completed successfully while 63 (24%) required a restart due to minor system failure. The proportion of setups which experienced minor failures dropped from 30% during the first week to 21% during the other three weeks. The results of the TRUE exercises are described in terms of training utility by Berger and Crane (1993) and comparisons of the DART and dome visual display systems by and Crane (1993). The focus of this paper is on network performance, utility of system components, and modifications to the system in response to pilot comments.

Network Analysis

Network traffic was captured for the final week of the TRUE to determine network loading and characteristics. Table 1 summarizes the data captured for the three engagement types used in the TRUE: basic fighter maneuvers (BFM), defensive counter-air (DCA), and offensive counter-air (OCA). The BFM engagements were one-on-one

Table 1. MultiRAD Network Utilization (Kbits/sec)

	BFM	DCA	OCA
Min	42	45	56
Max	204	294	337
Avg	50	73	87

fights between the two MDRCs. The average utilization for all engagements was less than one percent while the maximum utilization was never more than 3.4 percent. Additionally, the network exceeded 90 percent of the maximum values only two to three times per engagement. The network analysis done by the Laboratory showed no collisions, no cyclic redundancy check errors, and no alignment errors. This was probably due to the fact the network was not heavily loaded.

The largest number of PDUs on the network was the vehicle appearance PDU followed by the voice, radar, and emitter PDUs (See Table 2). The deactivate, fire, and impact PDUs are all event type PDUs and each took less than one packet per second during the TRUE. The network loading is consistent for the three different scenarios. The number of entities on the network is dependent on pilot input. The more ECM and missiles are deployed, the more entities are placed on the network. The average number of entities for each type engagement was 24 entities for each BFM, 38 entities for each DCA, and 39 entities for each OCA.

Table 2 Average Network Packet Utilization (Pkts/sec)

	BFM	DCA	OCA
Vehicle Appearance	30	38	47
Radar	1	4	4
Emitter	0	1	2
Voice	5	16	16

Remote Vehicle Approximation (RVA) algorithms were used to reduce the amount of data on the MultiRAD network. The algorithms use linear interpolation to determine a vehicle's new position. All moving entities on the network had RVA models of 10 meters long, 20 meters wide, 1 meter high, and 3 degrees rotational. If a model's delta between the actual position and RVA position exceeded 10% for any of these dimensions, an appearance packet was sent to all other vehicles on the network. The

RVA algorithms reduced network traffic by 65 to 85 percent over the course of the TRUE. Because tactics and maneuvers are different for each engagement, the effectiveness of RVA on network loading was also different for each engagement.

Although the network was near perfect, a hardware discrepancy in some of the NIU's ethernet boards was discovered early in the program that affected network reliability. The descrepancy was a result of the fact that the only contacts between the circuit board and the connector were solder joints on the pins. After repeated use of the connectors, the solder joints would fail, resulting in loss of data. This loss of data caused unpredictable operations on the network and large amounts of jitter. Once the connectors were repaired by the manufacturer, the problem was resolved.

Component Utility

F-15 Cockpits - The MDRC cockpits used by the TRUE pilots were rated as wholly acceptable for air combat training. The glass cockpit and touch panel were downrated only in that the displays were not positioned exactly as in the aircraft, and pilots had to scan for a moment to find what they were looking for. The lack of rudder pedals was cited as a problem only in close combat which was not a MultiRAD objective. A major difficulty, however, was that some of the *avionics software in the simulator was not* current with the aircraft. Pilots complained vigorously that the older software prevented them from using their weapons systems as they would in the aircraft. This lack of currency affected the pilots' tactics and greatly reduced the value of MultiRAD training.

Visual Display Systems - Pilots rated a wide field-of-view visual display system as necessary for effective multiship training even when the training objectives stressed beyond visual range tasks. Wide field-of-view visuals are necessary to maintain tactical formation, in transition from medium to short range weapons, to maintain mutual support, to disengage and reattack air targets, and to defend against surface-to-air missiles. Neither the DART nor dome were fully acceptable; however, the DART was preferred. While the AOI in the dome has higher resolution than the DART, the low resolution dome background would prevent a pilot from seeing his wingman without turning his head and searching with the AOI. Also, the DART's higher brightness and contrast increased pilot acceptance. F-15 or Su-27 size aircraft are reduced to an image of one or two pixels at 0.5 - 1 nautical miles. To increase the range at which aircraft could be detected and identified, a simulator unique effect (i. e., a simism) was introduced. At maximum visual detection range, an air target was represented as a white point light. At maximum identification range, enemy aircraft were represented as red point lights while friendlies were represented as blue, flashing lights. This simism greatly increased pilot acceptance; however, pilots continued to complain that they could not determine another aircraft's range or aspect until it was within 0.5 - 1 nautical mile.

Opposing Forces - Houck et al. (1989) found in the Advanced Air Combat Training program that the most significant training benefits came from the opportunity to engage multiple bogeys. However, in the first week of the TRUE, participants found so many flaws in the representation of opposing aircraft that they rated the training to have little or no value. TRUE pilots stated that both the manned and computer generated threat pilots had perfect situation awareness, flew aircraft that were too fast, had 360° radars which could not be defeated, and fired invincible missiles. Many of these problems were found to originate from aircraft and radar models used in the ATES which were generated from unclassified and widely available reference sources. While each parameter used in these *models may have been only slightly* optimistic, combining them all into a single threat model produced an unbeatable foe. Adjusting the threat model parameters using better data or pilot acceptance greatly increased MultiRAD training effectiveness ratings during the remainder of the TRUE.

One difficulty which could not be corrected was the infrared guided missile model used by the manned opposing forces pilots flying CETs. This model was originally developed for intercept training against a non-responding target. If the CET pilot has correctly positioned his aircraft with respect to the target, the missile scores a kill. When integrated into MultiRAD, however, the target aircraft's pilot would attempt to defeat the missile by effecting counter measures. These counter measures had no effect on the CET's missile. Pilots greatly objected to this aspect of MultiRAD simulation since it prevented them from practicing their skills at missile defense. The only corrective measure possible during the TRUE evaluation was to brief the CET pilots to hold their shots until the probability of a kill was very high. This solution satisfied no one.

Air Weapons Controller Station - Although the SCCENTS station provides only a functional representation of an AWACS or GCI display rather than a high fidelity physical simulation, the controllers who participated in the TRUE gave uniformly high ratings to the training provided by MultiRAD. During interviews, controllers stated that the SCCENTS station did present a number of simisms to which they quickly adapted. The most significant simism was that the simulated radar was too good. Aircraft altitudes were identified too precisely and there were no blind areas behind terrain features. The training value in MultiRAD came from the opportunity to practice several setups within a simulator period and then to debrief these engagements with the pilots while watching the video tapes and listening to their radio calls.

Debriefing Station - Pilots and controllers rated the computer system for controlling the synchronized videotapes as being overly complex. Only a few participants actually learned to use the system to its full advantage. Re-designing the system to make it fighter pilot friendly is a high priority item for improving MultiRAD. Aside from the complexity, however, pilots agreed with the controllers that reviewing video tapes of the engagement added greatly to the value of MultiRAD training. In particular, seeing the overhead view together with their own radar allowed pilots to evaluate the effectiveness of their actions in context of the entire mission.

LESSONS LEARNED

Functional vs. Physical Fidelity - Boyle and Edwards (1992) point out that, "A real program killer is unmet pilot expectations. If you are not simulating it, don't try to make it look like you are," (p. 496). This lesson was repeated during the TRUE in that functions which were incompletely modeled but were central to the missions being practiced raised the most serious objections. Notably, the lack of currency between the pilot's aircraft and the simulated F-15 software raised howls of protest. Pilots were compelled by the simulation to practice using tactics that they would not use if they were to go to war tomorrow. In this case, reduced fidelity was not good enough. Compare this response to the glass cockpit MDRC. The front panel was a CRT, there were no rudder pedals, and most switches were missing. None of these faults affected the mission and they caused no objections. Systems which were critical to the mission, hands-on-throttle-and-stick (HOTAS) controls and the displays used in air combat, were high fidelity simulations. The net effect was a fully acceptable trainer, except for the software. Air weapons controllers using the SCCENTS station had a similar experience. The physical similarity between the SCCENTS and an actual AWACS or GCI station was limited to the mission critical information on the display. Controllers adapted to the simisms caused by the non-critical elements of the SCCENTS and rated the system as providing high value training.

Integration of existing systems - The CET used as a manned opponent in the TRUE is a part task trainer designed to teach the shooter to intercept an air target and to put his aircraft into an optimal firing position. The objective of this part task trainer is to teach the pilot to make the intercept and to take a good shot. The missile model provides feedback to the pilot about his intercept: a good shot gets a kill and a bad shot misses. This missile model completely fulfills the CET's training objectives. The objectives of MultiRAD training, however, include training the F-15 pilot to defend against air-to-air missiles. The IR missile models used by the ATES were sensitive to flares and the target aircraft's throttle setting so that the F-15 pilot could, if he was quick enough, defeat an ATES missile. CET missiles were not designed to provide defensive training for the target aircraft's pilot and were therefore not responsive to flares or other counter measures. The CET's missile is not a low fidelity model within its intended application. Integrated into MultiRAD, however, the CET missile was unacceptable. Integrating existing systems requires very careful consideration of each system's original objectives and how that system operates. Networking existing systems will support effective training only if the objectives of the integrated system are clearly stated and the capabilities of the individual components are evaluated in terms of these objectives.

MultiRAD Network Limitations - The simulation network was not a limiting factor on the current MultiRAD system. Network utilization for the TRUE study never exceeded 3.4 percent of the full capacity of ethernet. With bandwidths of 100 Megabits/sec available for FDDI, the network should continue to fulfill the requirements of mission rehearsal and team training. The limiting factors found during the TRUE study were: host to NIU interface, NIU processing capability, and host computer processing capability. The MDRC ICDs were developed to maximize the amount of valuable information passed to and from the network. As the number of entities on the network increases, the simulator and NIU spend more time transferring and processing this data. Data minimization methods must be developed to optimize not only the data that is sent to and from the host but also the frequency of these transfers. Also, the network analysis showed the NIU spent the largest amount of time building up the host data buffer. For example, it took an average 49.5 percent (24.75 msec) of the total frame for the NIU to build the MDRC's data buffers. The primary restriction encountered in setting up the TRUE scenarios, however, was the physical limitations of the host simulators' computing power.

Test procedures and Configuration Control - As the integration process progressed, it became apparent that more testing and configuration control were needed. The time between the TRUE scenarios was not always adequate to thoroughly test changes to the overall system. Additionally, the integration effort was accomplished by four separate contractors and the government. Some problems occurred due to miscommunications between the integration teams while others were a result of misinterpretations of the protocols and ICDs. Still others were due to poor configuration control of software. Problems encountered and fixed would sometimes reappear in scenarios. Thorough test procedures and rigorous configuration control are crucial for an integration effort of this type.

LIST OF ACRONYMS

AAA--Anti-aircraft artillery
AOI--Area of interest
ARPA--Advanced Research Project Agency
ATES--Automated threat engagement system
AVTS--Advanced visual technology system
AWACS--Airborne warning and control system
BFM--Basic fighter maneuvers
CET--Combat engagement trainer
DART--Display for advanced research and training
DCA--Defensive counter-air
DIS--Distributed interactive simulation
ECM--Electronic counter-measures
ECCM--Electronic counter-counter-measures
FDDI--Fiber distributed data interface
GCI--Ground control intercept
HOTAS--Hands-on-throttle-and-stick
HUD--Head-up-display
ICD--Interface control document
IFF--Identify friend or foe
IR--Infra-red
MDRC--McDonnell Douglas reconfigurable cockpit
MultiRAD--Multiship research and development program
NIU--Network interface unit
OCA--Offensive counter-air
PDU--Protocol data unit
RVA--Remote vehicle approximation
RWR--Radar warning receiver
SAM--Surface-to-air-missile
SCCENTS--Simulated command control environment networked training system
SIMNET--Simulation Network

SIMVAD--Simulation voice analog digital
TRUE--Training requirements utility evaluation

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