Proceedings of the 1993 Winter Simulation Conference
G.W. Evans, M. Mollaghasemi, E.C. Russell, W.E. Biles (eds.)

TRAINING UTILITY OF MULTISHIP AIR COMBAT SIMULATION

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ABSTRACT

The Air Force's Armstrong Laboratory recently developed a distributed interactive simulation system. The purpose of this system is to support training effectiveness research involving combat skills. Currently, this simulation system provides the laboratory with most of the air combat simulation capabilities found in more expensive full mission simulators. This paper describes the training needs that lead to the development of this system and summaries the results of two operational training utility evaluations. The first of these evaluations used engineering research simulators at McDonnell Aircraft while the second used the laboratory's local area, distributed simulation network. Participants in both evaluations were mission ready pilots and air weapons controllers. Results of both evaluations show that pilots and controllers perceive similar training benefits in each simulation environment.

1 AIR COMBAT TRAINING NEEDS

Today's air combat pilot faces a difficult mission. Situation awareness must be maintained in spite of incomplete and often inconsistent data. Enemy aircraft must be found and destroyed. Communications and electronic jamming must be overcome. Enemy weapons must be defeated using countermeasures and maneuvers. In addition, the pilot must successfully execute these individual tasks as a member of an extended team of warfighters.

Training for this mission during peacetime is expensive and difficult. Most combat mission training occurs in unit level continuation training programs. These continuation training programs are the foundation of combat training. They provide the apprenticeship environment in which the pilots develop their skills through on-the-job training and practice. The unit's continuation training program gives pilots the opportunity to learn how to employ their weapon systems effectively and to practice as part of a combat team.

The cornerstone of a unit's continuation training program is in-flight training. Unfortunately, several factors combine to limit in-flight training opportunities for many combat skills (United States Air Force Scientific Advisory Board, 1992). These factors include security restrictions, safety of flight considerations, resources, and range space. In addition, resource and range space constraints also limit the opportunities for collective training as part of larger force units (Defense Science Board, 1976; 1988).

These training limitations suggest the need for additional training in many key mission areas. Operational pilots, training managers, and air weapon controllers have repeatedly stated their desire for additional training in many combat mission activities (Gray, Edwards, and Andrews, 1993; Houck, Thomas, and Bell, 1991). Table 1 shows eight of the combat mission activities for which pilots frequently request additional training opportunities.

Table 1: Mission Activities for Which Additional Training is Desired

Multi-bogey, four or more
All-aspect defense
Reaction to surface to air missiles
Dissimilar air combat tactics
Four ship tactics
Reaction to air interceptors
Employment of electronic countermeasures/counter-counter measures
Chaff/flare employment

Given the existing constraints on in-flight training, it is unlikely that in-flight training opportunities will increase. Therefore, we must identify additional training approaches that will increase combat training opportunities. One such approach is to use combat engagement simulations (United States Air Force Defense Science Board, 1992). Such simulations offer expanded opportunities to train weapon system employment and develop tactical proficiency. In addition, they offer new opportunities to train as part of a larger collective warfighting teams.

2 McDONNELL AIRCRAFT SIMULATIONS

Combat engagement simulations allow human warfighters and their simulated weapon systems to engage other warfighters on a virtual battlefield. These simulations are becoming increasingly realistic because of the continuing advances in computer and communication technologies. Perhaps the best known example of such combat engagement simulations is the simulator networking (SIMNET) program. This program was sponsored by the Advanced Research Projects Agency in cooperation with the Army. It showed the successful use of combat engagement simulation for the collective training of combat units (Alluisi, 1991).

Based on the potential of programs like SIMNET, the Armstrong Laboratory was directed in the late 1980's to evaluated multiship simulation for air combat training. The laboratory responded to this direction with a combined behavioral and engineering program conducted with the cooperation with the Air Combat Command. First, we identified potential weapon systems and mission activities that could benefit from multiship combat simulation. Next, before starting a long and potentially expensive development effort, we conducted an operational training utility evaluation using existing simulation facilities. The purpose of this evaluation phase was to learn if ground-based simulation was acceptable for combat mission training. To reduce costs and obtain information as quickly as possible, we used a two versus many air combat simulation at McDonnell Aircraft Company (MCAIR) in St. Louis, MO. We selected MCAIR for two reasons. First, they had an existing multiship simulation capability for a current Air Force fighter. Second, a training utility evaluation based on the Air Force's current air superiority fighter was directly applicable to the Advanced Tactical Fighter training system.

2.1 MCAIR System Components

The simulation system used at MCAIR was designed to support engineering development. Its design and equipment represent the full mission simulator facilities developed by aircraft manufacturers in the late 1980's.

Figure 1 shows the principal components of this system. Each F-15 cockpit was located in a forty-foot diameter dome. The visual world was created by a combination of CompuScene IV image generators and video target projectors. Enemy surface to air and electronic jammers were provided through a computer based threat system. Enemy aircraft consisted of both piloted and computer-controlled adversaries. The manned enemy aircraft were flown using low fidelity manned interactive control stations. Human participants on both sides were supported by air weapons controllers.

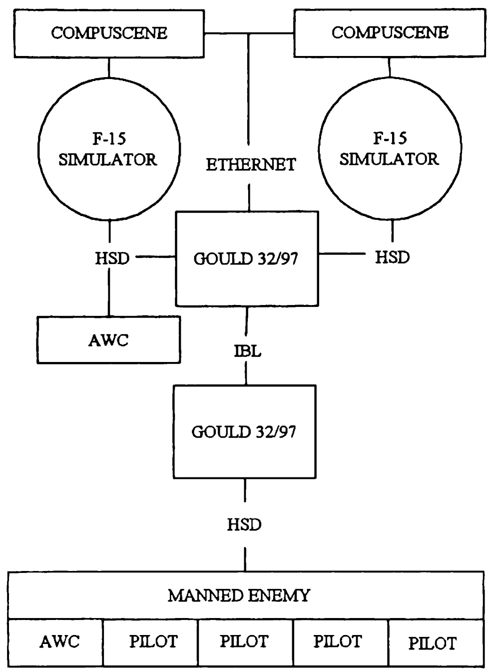

Figure 1: McDonnell Aircraft Simulation Components

Two Gould 32/97 super minicomputers served as the host computers for this simulation. An Inter-Bus Link connected these two Gould computers. The simulators and other peripheral devices were connected to these computers by High Speed Devices and Ethernet. A more detailed description of this simulation is available in McDonnell, Broeder, and Cutak (1989).

2.2 Training Utility Evaluation

Fourteen weeks of air combat simulations were flown. Each week consisted of four days of simulated combat missions. An average of twelve pilots and six air weapons controllers took part in each training week. The participants flew as a formed team for the entire week. Each formed team consisted of a flight lead and wingman from the same fighter squadron and an air weapons controller. The team flew at least one simulator sortie each day. Each simulator sortie lasted about one hour and involved a specific air combat mission (e.g., fighter sweep, point defense, force escort).

The simulator training was designed using a building block. This building block approach involved individually manipulating mission difficulty for each team based on their performance. Mission difficulty was controlled by varying threat capabilities, weather, electronic and communication jamming, and threat tactics. Each team typically flew four separate combat engagements in the hour sortie. A more detailed description of this evaluation is available in Houck, Thomas, and Bell (1991).

Pilots and air weapon controllers received feedback about their mission performance through a variety of sources. Within each simulator all systems and displays responded appropriately. Engagement results produced real-time outcomes that included kill-removal and battle damage. The visual system allowed the pilot to see the missiles, tracers, other aircraft, and explosions. All communication between the pilots and between the pilots and the air weapons controller was recorded. The radar warning receiver and radar displays were recorded from each cockpit. This information was combined with a plan-view display of the engagement to support the team's post-mission debrief. In addition, an instructor pilot monitored their cockpit instruments and voice communications from the test director's station.

The responses of both pilots and air weapons controllers were extremely positive. Table 2 shows those combat activities pilots felt were better trained in this multiship simulation than in their unit training program. These combat activities include the same combat activities that are difficult to train in-flight because of resource limitations, security restrictions, and safety constraints.

The pilots also identified several combat activities for which their unit training program was superior to this multiship air combat simulation. These activities, listed in Table 3, require high visual resolution. Even though the MCAIR domes provided target and laser projection systems that were state-of-the-art, they still could not provide the pilots with enough resolution to enable them to see the visual cues they rely on in their in-flight training.

2.3 Conclusions

The results of this operational training utility evaluation show the potential value of using simulators to help train air combat. Both Air Force pilots and air weapons controllers reported that multiship air combat simulation provided better training for many combat activities than their current unit training program.

Table 2. F-15 Mission Activities for Which Multiship Simulator Training was Rated Significantly Higher than Unit Training.

Multibogey, four or more
Reaction to surface to air missiles
Dissimilar air combat tactics
Employment of electronic countermeasures/counter-counter measures
All-aspect defense
Escort Tactics
All-weather employment
Communications jamming
Low altitude tactics
Threat warning assessment
Work with air weapons controller

Table 3. F-15 Mission Areas for Which Multiship Simulator Training was Rated Lower than Unit Training.

Visual lookout
Tactical formation
Visual identification
Mutual support

3 DISTRIBUTED INTERACTIVE SIMULATION IMPLEMENTATION

Although the training utility evaluation showed that multiship simulation could complement continuation training for many critical combat activities, the Air Force could not afford to buy and maintain a system such as the one used at MCAIR. Therefore, more affordable alternatives must be developed and evaluated if multiship simulations are to become an integral part of continuation training.

The Multiship Research and Development (Multirad) program at Armstrong Laboratory, Aircrew Training Research Division was undertaken to create a system that would provide multiship air combat simulation using lower cost, distributed simulation. One of the goals of the Multirad program was to develop a simulation testbed using a SIMNET type approach that would support training effectiveness research. Once the simulators were integrated into the Multirad distributed simulation network, a series of training exercises known as the Training Requirements Utility Evaluation (TRUE) was conducted. The purpose of the TRUE, which replicated many elements of the MCAIR advanced air combat simulations, was to find out if we had created an acceptable simulation of two versus many air combat.

3.1 MultiRAD System Components

Unlike the simulation at MCAIR in which each participant entered the virtual battlefield through a master computer, the participants in SIMNET create their virtual battlefield from the information flowing on a distributed simulation network. Each simulator is a stand alone device that broadcasts its own state to the rest of the network while presenting the state of the other simulators to the operators. Compared to the system of super minicomputers at MCAIR, the SIMNET approach to multi-player simulation is lower cost and more easily maintained. However, SIMNET was developed for ground warfare where the battlefield is typically less than 20 x 20 km, there are no guided munitions, no radar, no electronic countermeasures or jamming, and the players move at less than 50 km/hr. Air combat simulation requires a much larger battlespace plus simulation of many types of interactions among players that are not included in SIMNET. The objective of TRUE was to determine whether the training benefits shown at MCAIR could be realized using a modified version of SIMNET.

The Multirad system is composed of several independent devices connected through network interface units (NIUs) to an ethernet communication channel. The NIU provides a method for communicating between the host simulator and ethernet using a SIMNET compatible communications protocol. The Multirad components used in TRUE were: two F-15C cockpits integrated with computer generated imagery and wide field-of-view display systems, an air weapons controller station, two red fighter cockpits, a computer generated threat system, an exercise control station, and an independent video debriefing system (see Figure 2).

3.1.1 Blue Force

Each blue team consisted of two F-15 pilots and an air weapons controller. Each team flew a variety of combat missions patterned on the missions flown in the earlier evaluations conducted at MCAIR.

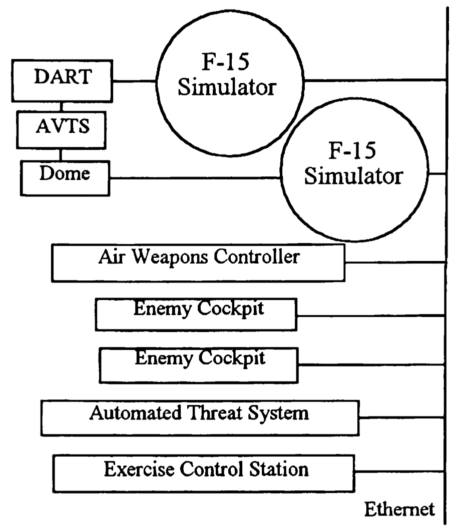

Figure 2: Distributed interactive simulation implementation of multiship simulation.

The two F-15C cockpits were McDonnell Douglas Reconfigurable Cockpits (MDRCs) which incorporate stick and throttle controls with a color screen/touch screen front panel. Each MDRC provides full mission fidelity for air-to-air combat and is based on the simulator software used in MCAIR's full mission F-15 simulators. Included are high fidelity aerodynamics, air-to-air radar, weapons, electronic counter measures (ECM), radar warning receiver (RWR), communications, and head-up display (HUD). The MDRCs have no rudder pedals nor provisions for take-off or landing, refueling, or emergency procedures.

Imagery was generated by the General Electric Advanced Visual Technology System (AVTS). One MDRC was located in a 24-foot diameter dome. This dome had three forward channels of background imagery and one higher resolution area of interest channel that was head slewable throughout the dome. The second MDRC was installed in the Armstrong Laboratory Display for Advanced Research and Training (DART). The DART is a dome-like system consisting of eight segments of a dodecahedron which surround the cockpit. Each segment is a rear-projection screen approximately one meter from the pilot's head. During the TRUE, imagery was provided to only six of the screens as controlled by a head tracker. Unlike a pilot in the dome, a pilot in the DART could not see to the six o'clock position. A more detailed description of these displays is available in Crane (1993).

Each team of F-15 pilots was supported by an air weapons controller using a generic workstation.

3.2 Development and Integration

One of the design goals of the Multirad project was to develop a distributed simulation network that would include simulators of varying fidelity from different manufacturers. Many of the devices incorporated into Multirad were stand-alone simulators that were not designed for network operations. Likewise, the SIMNET communication protocol was not designed to support aircraft simulation. The major difficulty in developing Multirad was to adapt these existing systems and protocols to meet the requirements of multiship air combat simulation.

3.2.1 Communications Protocol

The entire Multirad network was designed as a distributed simulation network. Each device was connected to the network by means of a network interface unit (NIU). These NIUs served as the communication gateway between each device's host computer and the SIMNET-based Multirad network.
The NIU's primary functions include coordinate system conversion, Remote Vehicle Approximation (RVA), data filtering, and conversion of units of measure. Network communication between devices as based on SIMNET version 6.6.1 Protocol Data Units (PDUs). Additional PDUs to support radar, emitter, and freeze were defined by Armstrong Laboratory to support air combat simulation. RVA was incorporated into the vehicle appearance PDU to reduce network traffic. The position of each vehicle is dead reckoned linearly in time based on its position, heading, altitude, and velocity in the last PDU.

3.2.2 Difficulties in DIS Implementation

In the early stages of Multirad development, vehicle jitter was a significant problem. Initially, jitter was attributed to RVA updates. However, other sources of jitter were identified including coordinate conversion and precision, different devices operating at different frame rates, and NIU overload. Conversion coordinate algorithms were modified and fewer vehicles were used in some of the mission scenarios to reduce NIU overload. With these modifications, the remaining jitter caused by RVA updates is only noticeable when flying in close formation and was deemed acceptable. A smoothing algorithm was considered but not implemented to due to system loading.

Other difficulties were discovered only during system testing. Improper memory management caused the appearance of ghost vehicles on the network or a vehicle retaining attributes from one sortie to the next. Problems were also uncovered in the interactions among players. Unrealistic kills were observed such as gun shots from 80 miles or missiles with uncanny homing ability. Some of these problems resulted from improper threat models but others resulted from network integration such as impact messages which were interpreted as kills regardless of other information such as the range from the shooter.

3.3 TRUE Evaluation

The TRUE consisted of four, one-week training exercises which were modeled on the MCAIR simulations. Teams consisting of a lead pilot, a wing pilot, and an air weapons controller 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.

Twenty-three, USAF, F-15 pilots and 13 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.

4 TRUE RESULTS AND LESSONS LEARNED

During the TRUE exercises, 267 multiship missions were conducted with 63 missions (24%) requiring a restart due to systems failure. The restart rate dropped from 30% during the first week to 21% during the remaining three weeks. Network traffic averaged less than 1% of capacity and peaked at 3.4%. Analysis of network traffic found no collisions or other network errors.

4.1 Evaluation of Multirad System Components

The MDRC F-15 cockpits were rated by pilots as wholly acceptable for air combat training. Neither the glass cockpit and touch panel nor the lack of rudder pedals were cited as serious problems. A major shortcoming with the MDRC was that the radar software in the simulator was not the current software revision used in the aircraft. The older software would not allow pilots to employ their weapons in the same way that they would in actual combat. The result was that pilots had to modify their tactics to use the simulator. The lack of currency was cited by pilots as the most significant problem with Multirad training.

Pilots rated wide field-of-view visual displays as necessary for air combat training even though the TRUE scenarios emphasized beyond visual range combat. Pilots used visual cues to maintain tactical formation, defend against surface to air missiles, provide mutual support, disengage and re-attack air targets, and to transition from medium to short range weapons. Neither of the display systems used in TRUE was rated as completely acceptable. The resolution in the dome's area of interest (AOI) was higher than the resolution throughout the DART. However, pilots found the head-tracked AOI distracting and could not see a target or a wingman without looking directly at it. The DART's wider field-of-regard, and higher brightness and contrast were preferred to the dome's higher AOI resolution. In both displays, aircraft could not be clearly seen until within 0.5 - 1 nautical mile. Beyond one mile, aircraft were depicted as point lights. Pilots could detect aircraft as point lights but could not determine aspect, heading, or closure.

Simulation of red force aircraft received mixed reviews. Initially, both manned and digital air threats were described by TRUE pilots as invincible with perfect radar, total situation awareness, and warp drive engines. These evaluations were used to modify the threat model parameters until the pilots were satisfied that the threats were credible. One aspect of red air which could not be corrected was the air-to-air missile used by the CETs. These missiles did not include a model of the infrared seeker head and could not be defeated by flares or maneuvers. Pilots found the inability to practice missile defense unsatisfactory. Pilots rated the depiction of surface to air missiles (SAMs) as providing valuable training but could not evaluate the fidelity of the simulation.

4.2 Pilot Evaluation of Multirad Training

Pilots were asked to rate the quality of training received in their current units and in the Multirad simulation for 30 tasks. Tasks which were rated higher in Multirad than unit training were employment of electronic counter measures, employment of chaff and flares, defense against SAMs, work with an air weapons controllers, and engagements against four or more enemy aircraft. Tasks which were rated significantly lower in Multirad than in current unit training were tactical formation, visual lookout, mutual support, and visual low altitude flight. These tasks place heavy demands on visual imagery and precise handling qualities of the aircraft.

4.3 Lessons Learned

Pilot evaluations of the Multirad system demonstrate the concept of selective fidelity. The MDRC cockpits has a CRT/touch screen front panel, no rudder pedals, and is missing most switches. However, the functional fidelity of the simulated cockpit systems plus the physical fidelity of the stick and throttle were sufficient to support effective air combat training and earn high ratings from pilots. Similarly, while the air weapons control station did not physically resemble any operational control station, controllers quickly learned to use it and rated the training received as extremely valuable. On the other hand, the simulation of the F-15's radar was very high fidelity but not current with the software revision currently used in the aircraft. This seemingly minor flaw raised much more strenuous objections than the physical configuration of the MDRC because the older software would not allow pilots to employ their weapons as they would if they were to go to war tomorrow.

Integrating the CETs with the MDRCs pointed out a difficulty with creating a DIS training network. The CETs were designed as stand alone devices to train the pilot to conduct an air intercept and to maneuver into an acceptable firing position. The missile model is therefore based solely on the relative positions of the CET and target aircraft. If the position is good enough, the missile scores a kill and the pilot is reinforced for the intercept. The limited fidelity missile model fully supports the training objectives of the CET. In the Multirad network, the training objective is for the F-15 pilot to practice multiship combat skills including defense against air-to-air missiles. Since the F-15 pilot cannot defeat a CET missile regardless of the correctness of his or her actions the pilot receives little training benefit. Integrating existing systems using DIS requires very careful consideration of the capabilities of each system with respect to the training objectives of the network. Successful individual trainers may not integrate into a successful network.

5 MODIFICATIONS TO MULTIRAD

Threat simulations used in Multirad were modified during TRUE to increase pilot acceptance. While each parameter used in threat modeling may have been only slightly optimistic, combining these parameters into a single model produced an undefeatable enemy with highly unrealistic capabilities. Threat models were modified to comply with the best information available about the systems being simulated and to respond accurately to the F-15 pilot's actions.

A 6 o'clock window has been added to the DART providing a nearly full field of regard. The MDRC cockpit in the full field-of-view dome has been moved to a smaller version of the DART for further evaluation. The head-slaved AOI was not successful in supporting air combat training because the low resolution of the background imagery prevented pilots from using their peripheral vision to detect air targets. A pilot in the dome had to search for targets by sweeping his head back and forth to direct the AOI to an area where a target might be located.

6 CONCLUSIONS

There is a growing realization that combat mission training cannot be fully accomplished using in-flight training. The evaluations conducted at MCAIR and Armstrong Laboratory demonstrated the experienced pilots and air weapons controllers perceive multiship air combat simulations as providing additional air combat training opportunities beyond current unit training. Multiship simulation provides pilots and controllers the means to practice tasks which cannot be practiced in the aircraft due to cost and peacetime training restrictions.

Multiship air combat simulations using a super-minicomputer, shared memory architecture were successfully transitioned to a distributed microprocessor architecture using a communications system which is compatible with other military trainers. While this transition has provided high level training using low-cost devices several limitations remain. Most notably, the out-the-window visual simulation cannot provide the level of resolution necessary to judge aspect and closure of air targets at realistic ranges. Also, the opportunity to integrate existing training devices into a multi-player network may create new difficulties. Each device's capabilities and level of fidelity needs to be carefully considered with respect to the training objectives of the integrated system. Ill-considered choices may degrade rather than enhance the quality of training.

REFERENCES

Alluisi, E. A. 1991. The development of technology for collective training: SIMNET, a case history. *Human Factors*, 33: 343-362.

Crane, P. M. 1993. Evaluation of two wide field-of-view display systems for air combat training. In *Eurodisplay '93: 13th Annual International Display Research Conference*, Le Club Visu, Lannion, France.

Defense Science Board. 1976, February. Summary Report of the Defense Science Board Task Force on Training Technology. Washington, DC: Author.

Defense Science Board. 1988, May. Report of the Defense Science Board Task Force on Computer Applications to Training and Wargaming. Washington, DC: Author.

Gray, T. H., Edwards, B. J., and Andrews, D. H. 1993. A survey of F-16 squadron level training in PACAF. (AL-TR-1993-0041). Williams Air Force Base, AZ: Armstrong Laboratory, Aircrew Training Research Division.

Houck, M. R., Thomas, G. S., and Bell, H. H. 1991. Training evaluation of the F-15 advanced air combat simulation. (AL-TP-1991-0047). Williams Air Force Base, AZ: Armstrong Laboratory, Aircrew Training Research Division.

McDonnell, G. W., Broeder, R. F., and Cutak, R. J. 1989. Multi-Ship Air Combat Simulation. In *Proceedings of the 11th Interservice/Industry Training Systems Conference*. Ft Worth, TX: National Security Industrial Association.

Rogers, B. 1992. Tactical Air Threat System for a Distributed Simulation Network. *Proceedings of the 14th Interservice/Industry Training Systems and Education Conference*. San Antonio, TX: National Security Industrial Association.

United States Air Force Scientific Advisory Board. 1992, December. Report of the Support Panel of the Air Force Scientific Advisory Board Ad Hoc Committee on Concepts and Technologies to Support Global Reach - Global Power 1995 - 2020. Washington, DC: Author.

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