Live, Virtual & Constructive Simulation for Real Time Rapid Prototyping, Experimentation and Testing using Network Centric Operations

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Abstract

The use of live platforms, real time virtual simulators and constructive entities have been used to provide improved systems engineering requirements and to allow customers to be involved during the entire development and test process. As an example, a series of Network Centric Operations (NCO) experiments were conducted by providing operators knowledge (information, data) from geographically separated groups, faster and in a more meaningful way, than previously possible to facilitate rapid prototyping, operator decision making and coordinated action. Improved information processing and transfer between sensors, analysts, decision makers and effectors made this possible along with improved bandwidth of the network and the use of a "truth data" network using Distributed Interactive Simulation (DIS). The use of an Internet Protocol (IP) network at the tactical edge was also rapid prototyped after initial testing using a basic Link 16 network taking advantage of new applications on existing networks. Fielded systems, such as the F-15, F/A-18, tilt rotors vehicles, helicopters and Unmanned Air Vehicles (UAV)s were used in several experiments together and separately, using different types of tactical communications from Joint Tactical Information Distribution System (JTIDS) / Multifunctional Information Distribution System (MIDS) to a combination of Extensible Markup Language (XML) over IP. Advanced wireless communication systems such as a software programmable radios, satellite communications and network waveforms were utilized to provide the IP network from the battlefield all the way back to Continental United States (CONUS). Even though some of the platforms do not have IP communications systems installed, much of the network data could be routed through actual hardware so, onboard the flight test platforms, in the high fidelity simulations in the laboratories, and operators could observe the effects of improved situational awareness and operations as if the systems were fielded to be able to test the effects of the network. Scenarios were developed and tested as part of several large live, virtual, constructive simulations involving flight test aircraft, many simulators from different locations with different levels of fidelity and additional constructive entities over a four year period. This paper will describe the development of the live, virtual, and constructive simulations, the results obtained, and future planned usage using real time simulators to provide a rapid prototyping capability to support the development and testing of future concepts.

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I. Introduction and Previous Experience

Military engineering flight simulators are built to provide rapid prototyping, development, testing, and / or training environments for aircraft development, integration, flight testing and operations. These flight simulators support many phases of the Systems Engineering VEE as shown in Figure 1.[i]

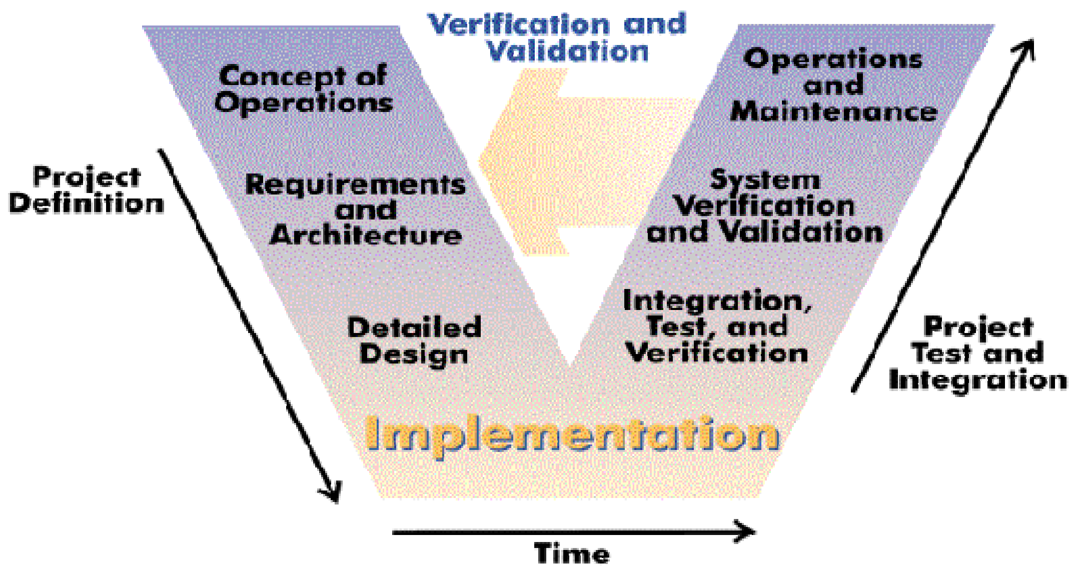


Figure 1 Systems Engineering VEE

In the past, "live" simulation and training was the predominant method by which the Warfighter evaluated the weapon system design, tactics, and maintained his/her readiness posture.[ii] This requires employment of a large number of operational assets, training, and support personnel to achieve the objectives. The use of flight test and "live" training was done in conjunction with high fidelity, costly simulators installed at the military installations or at the contractor development site, which are also starting to be used for distributed mission training. An example is of a military training simulator[iii] shown on Figure 2.

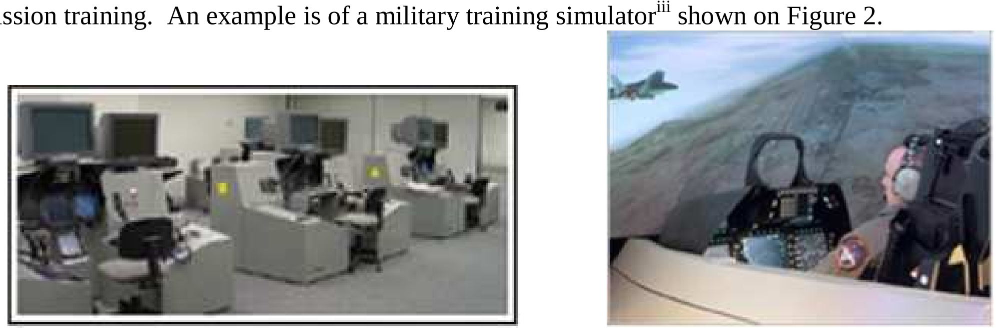


Figure 2 Military Flight Simulators

Today, there is a migration toward a cost effective mixture of simulators at different levels of fidelity and the use of Live, Virtual, and Constructive (LVC) entities operating in a common real/synthetic environment. By having this type of capability, many phases of project definition, integration and testing can and are supported by all types of engineering and flight hardware simulators as shown on Figure 3. In some cases, the requirements are defined by the customer and the contractor, hardware and software designed and built, integrated and tested to see if it meets the original requirements. Many times there are problems because of misunderstandings, incomplete requirements or there were unknown relationships between the requirements that were not captured. This is shown as the Green "Customer" boxes on Figure 3.

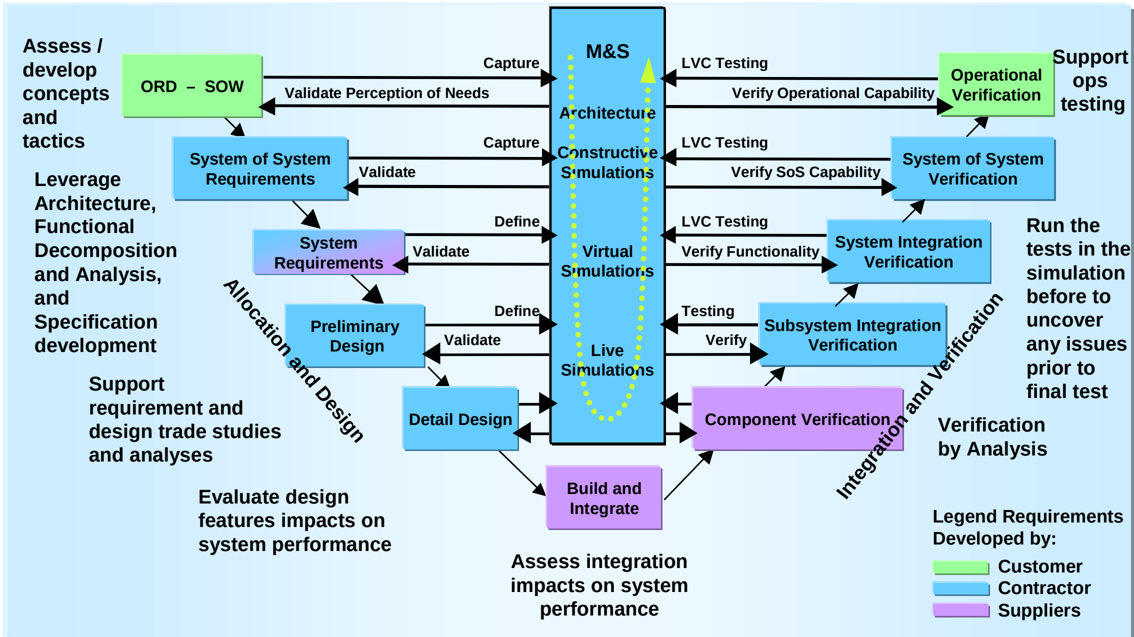


Figure 3 M&S supports SE phases and leverages SE architecture

A better way has been shown by having the customer involved in the rapid prototyping, development, integration and testing, using Modeling and Simulation, during all phases of the process. In that way. scenarios can be used to see what the advantage and CONOPS are of the new concept, refinement of the requirements and design, early integration of the concept on a flight test aircraft, and then to use the simulation as part of the certification process. In the end, the same operational tests will have been done in the simulation before and expected results known long before the real hardware and software have been tested.

As an example several rapid prototyping simulations were used to show the capability and the concept. This was first demonstrated by Boeing during its Enterprise Network Centric Operations (ENCO) Experiment in November 2003.[iv] The objective for this experiment was to demonstrate Boeing's LVC capabilities within a Synthetic Environment, the distributed integration of high fidelity simulations, and it's new Network Centric Operations and network capabilities to support the "Digital" Warfighter in the 21st Century to accelerate experimentation, test and evaluation, training and maintain increased readiness. Today, the emphasis is on how the simulator can provide development and testing on a complete flight of aircraft and / or provide the capability to perform mission rehearsal with a large number of participants through Distributed Mission Training (DMT)[v]. Part of that capability is to have not only the simulators linked into a network with many other virtual and constructive models, but to allow actual aircraft, flying on or off a range, to participate in a large exercise scenario. This combining of live, virtual, and constructive models has lead the way to Live, Virtual, Constructive Operations capabilities, which now give the Warfighter a cost effective way to get the most research, training, or operational capability using Link 16[vi].

There are limitations to the amount of information that pilots have available to them during exercises, such as "Red Flag"[vii]. When only "live" assets are used, there are often limitations on the systems that can be exercised, due to environmental or for security reasons, but they are equipped with systems that provide an offensive capability. Using some of the techniques discussed here, there is the capability to allow live flight assets, ground based simulators, and digitally generated platforms to all interact within a common environment in a realistic scenario. This is the concept of live, virtual, constructive integrated simulation as shown on Figure 4.

Figure 4 Live, Virtual, Constructive Research, Operations, Testing, and Training

In some cases, the flight assets participating in an LVC scenario do not have enough data being transmitted to the ground simulator to allow them to participate with the rest of the simulation assets. Developing that data was the subject of a previous paper[viii]. Algorithms were developed for a real time flight simulation to provide the visual and sensor representations of flight test entities in the simulation without the need to add telemetry pods to the flight test assets. By obtaining the Global Positioning System (GPS) positions, heading and total velocity, an accurate representation of the vehicle could be determined and shown in the overall simulation. The common basis for all the vehicles was Distributed Interactive Simulation (DIS) to allow all entities to see each other and provide "truth" information for the simulation.[ix] The algorithms developed were used to translate flight test information that was available and use it to estimate the information needed to provide a valid DIS entity state. The simulation users could then observe and interact with the flight test entities visually or using their sensors. There was some lag between the actual flight test position and the DIS "truth" position, but through the use of these algorithms excellent correlation and behavior between them was maintained.

Boeing's 2003 Enterprise NCO Experiment was part of their evolving integration of Live, Virtual, and Constructive development concept and was intended to be a small, but significant step on the path to fully integrated live, virtual, and constructive training environments. Only one live asset was used and the telemetry data was transmitted to the ground as a Link 16 message. Data latency and smoothing were still issues, but the Euler angles and positions were easily determined from the inertial navigation data contained in a Link-16 message. In addition, the flight hardware aircraft could deliver weapons, but the weapon delivery was modified to have the Weapon System Operator press an alternate weapon release button that was read across the Link 16 interface that sent a signal to the ground to launch, drop, and score the Joint Direct Attack Munitions (JDAM)s. These requirements were met by developing a networked approach to bring the "best" engineering simulators together with "live" flight assets, and the constructive models to give the crews the look and feel of a large battle. The network and some of the simulators are shown on Figure 5.

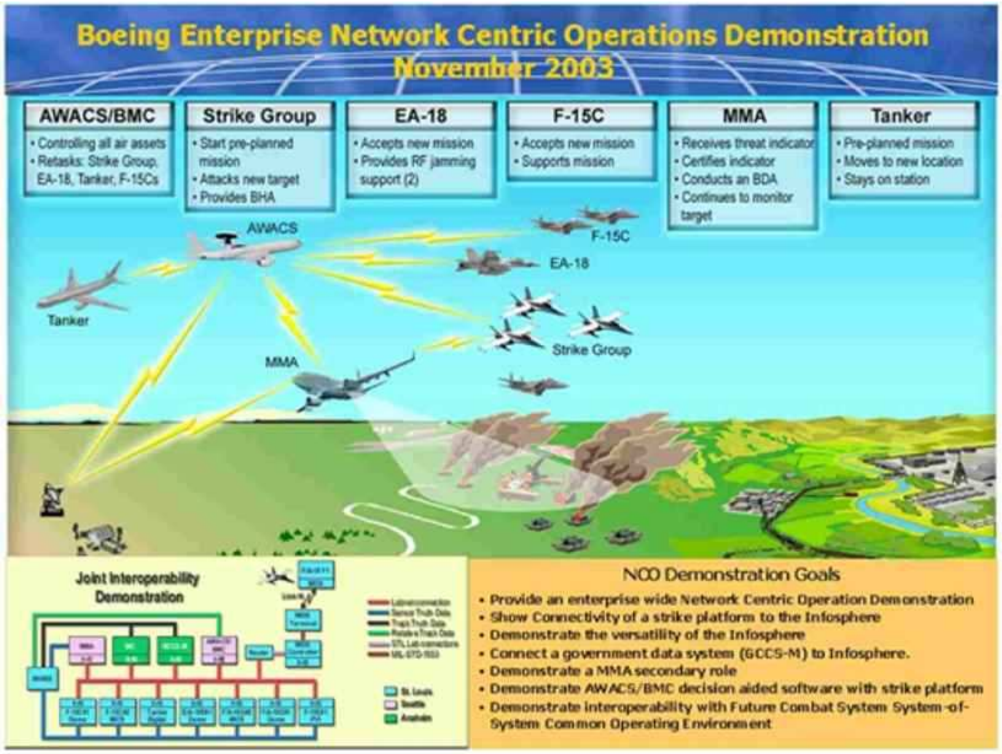


Figure 5 2003 Network Centric Operations Experiment

Since the flight test aircraft flew out of St. Louis, an area of Missouri was used with correlated visuals and sensors.

In 2004, a second Enterprise Network Centric Experiment was conducted. Additional flight assets were added as well as more sites and entities as shown on Figure 6.

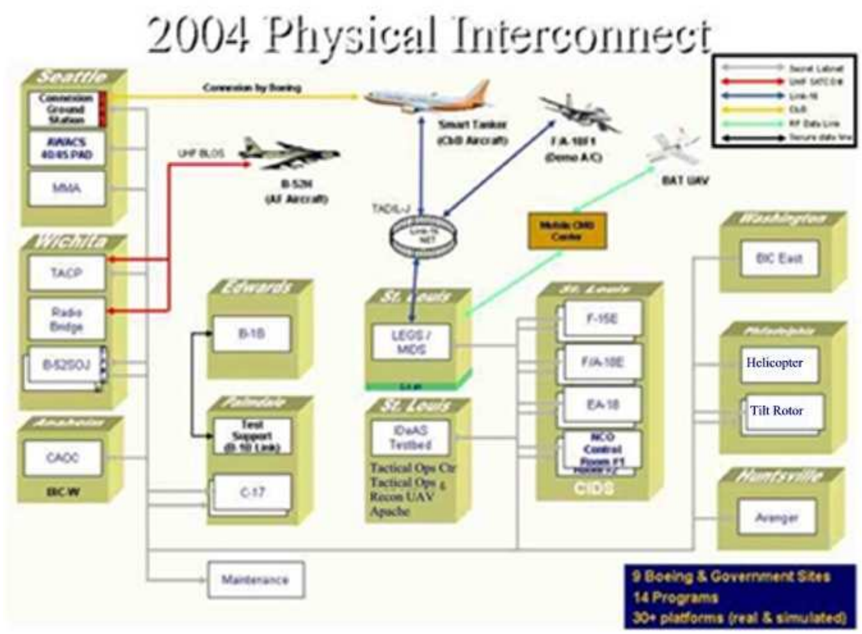


Figure 6 Enterprise NCO Experiment Assets

The scenario was again centered on the St. Louis area, since some of the flight assets and most of the simulations came from that location. The scenario for the experiment was more involved this time and included three different operational cells working together in a network centric operations environment as shown on Figure 7.

Figure 7 2004 Enterprise NCO Experiment Scenario

The F/A-18 F-1 had a special message that contained the Euler angles, GPS positions, and velocities, so its position could be computed. The BAT[x] Unmanned Air Vehicle (UAV) and the Connexion airplane did not have that capability and generated their position, total velocity, and heading at a slower rate that was used to successfully generate DIS entity states for them and will be expanded on below.

The absolute accuracy of the resultant DIS entities was not measured, but comparing the imagery sent back from the BAT UAV as it flew over ground targets, showed both smooth operation on the displays and good correlation with the position and Euler angles as shown on Figure 8.

Figure 8 Views from Sensor and Genview of BAT

The 2005 Enterprise NCO Experimentation provided the means to demonstrate the technology that enables fielded systems to connect into an NCO environment and how they can be integrated with future systems and advanced Command and Control (C^{2}) technology.[xi] For 2005, all platforms were assumed to be equipped with new radios allowing them to be use Extensible Markup Language, which goes by the abbreviation XML for message passing.

Scenario

Lessons learned from the 2004 NCO Experiment indicated that a scenario with a single execution thread and duration of approximately one hour would be more meaningful for the target audience and make the connection between advanced technologies and mission capabilities clearer. The 2005 scenario was therefore focused on a single thread containing six sequential events revolving around an urban ground operations mission utilizing dismounted soldiers with supporting airborne assets. The Boeing site at Palmdale, CA was chosen as the center of the live urban scenario activities. Boeing Palmdale had the necessary buildings, ground vehicle operating areas, frequency clearances, LabNet connectivity, Unmanned Air Vehicle (UAV) hanger, and support facilities to host the scenario events.
The six discrete events are outlined as follows.

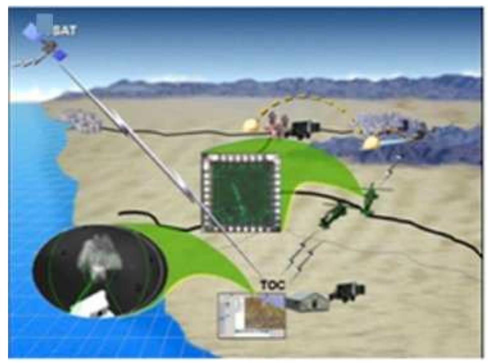
Event 1 – Sensor-Shooter Fused SAM Detection and Engagement

At the start of the scenario, a pop-up Surface-to-Air (SAM) site is detected by a UAV flight and F-15s flying a CAP (Combat Air Patrol) mission. This threat has to be eliminated before troops can be positioned and begin conducting ground operations. Sensor reports from the aircraft were sent to command and control via Cursor on Target (CoT)[xii] messages over IP-based networks using XML. In the case of the F-15, the IP network capability was provided by live radio hardware using a networking waveform. Once the sensor reports were fused and an accurate location of the SAM site was determined, the C^2 node performed a weapon target pairing and sent a mission attack assignment to the UAV ground station. The UAV ground station developed a mission plan autonomously and executed the attack using Small Diameter Bomb (SDB) precision munitions. When the threat was eliminated, a transport helicopter was released to proceed to the forward assembly area with a helicopter escort to drop off troops and supplies needed to setup and begin operating a checkpoint outside of the urban area.

Event 2 – Multilingual MLS Translation and Collaboration at Checkpoints

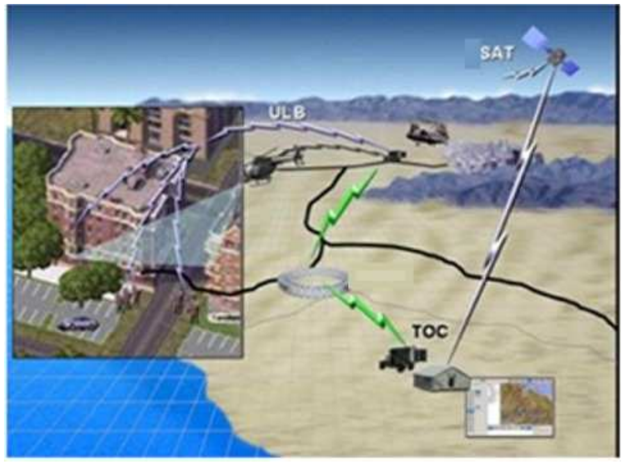
A local vehicle approached and was stopped at the coalition checkpoint. The driver was questioned in his native language by a soldier using the Mediator language translation system. Questions asked included: “what is your name?”, “where are you going?”, “where do you live”?, etc. The driver answered the questions verbally in his natural language and his translated answers as well as his photo were sent from the Mediator tablet PC over the 802.11 wireless network to a Humvee vehicle and ultimately over the satellite link to a remote intelligence analyst station where the data was analyzed. When the answers raised suspicion that the driver was concealing his true identity and travel purpose, an alert message was sent to the checkpoint Mediator terminal through the reverse network path. The vehicle was allowed to pass through the checkpoint, but an UAV was tasked to follow the vehicle and provide video surveillance. The video feed from the UAV was received by the Open Mission Management (OMM) ground station and images were published on the network and were available at all command and control stations. The vehicle was followed and stopped at a building which was a suspected IED (Improvised Explosive Device) manufacturing facility. The UAV remained on station to monitor and report on anyone entering or leaving the building.

Event 3 – Unmanned/Manned Aerial Vehicle Performing Full Spectrum Support



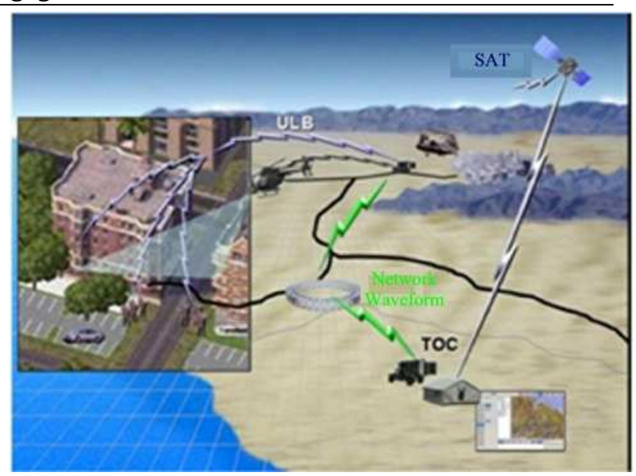
After finishing the escort mission for the transport helicopter, the helicopter and UAV team continued on a patrol mission. The UAV detected a mortar launch flash about 15 kilometers north of the checkpoint. The helicopter calculated and reported the position of the mortar launch to C^2 over the network. At the same time, the checkpoint reported hostile fire and requested air support. The C^2 node tasked the helicopter to fire on the mortar position. The helicopter vectored the UAV to a fire position and directed the UAV to launch on the hostile vehicle before it flees into the urban area. The helicopter used its sensors to provide a Bomb Hit Assessment (BHA) image of the target after the strike to verify the kill and sent the image to the C^2 node over the network.

Event 4 – Persistent Tactical Intelligence, Surveillance and Recon (ISR) and Dismounted Blue Force Tracking



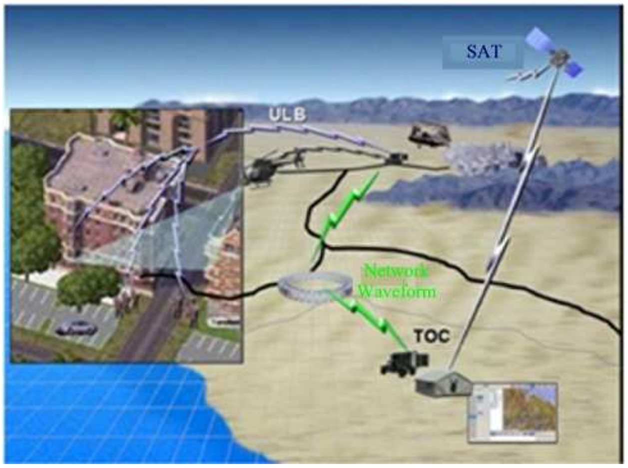
Ground troops were deployed to the Improvised Explosive Devices (IED) meeting location to contain the building and capture the high value target. The squad commander was positioned in the Humvee command center. He had access to the video surveillance feed from the orbiting UAV via the high-speed network in the Humvee. He also had information on the position of each of the dismounted soldiers via blue force tracking. The position data from the individual soldiers was sent to the commander directly over a low power and low probability of intercept local network. The position data was relayed over the network to the C^2 node where it was published and available for display by any node on the tactical network. The result was that friendly troop positions were displayed on all the C^2, F-15, and helicopter displays, so that all would have improved situational awareness if needed for close air support.

Event 5 – Rotorcraft Extended Range Threat Engagement



The helicopter and UAV team continued on patrol and discovered a suspicious looking convoy of vehicles heading toward town as predicted by intelligence analysis. The UAV sent video of the convoy back to C^2 for identification. C^2 authorized the helicopter to engage the target vehicles in the convoy. The helicopter fired Hellfire missiles from a standoff range and the UAV provided video of the strike back and relayed it to the C^2. In the scenario, the convoy made a cell phone call to the suspect in the IED building and alerted him of the attack. The suspect (high value target) fled the building to evade capture by coalition troops.

Event 6 – Threat Identification, Pursuit and Containment in Urban Terrain



The suspect fled the IED building in the same vehicle he arrived in. The UAV followed the vehicle and provided video surveillance and tracking information to the Open Mission Management (OMM) ground station. OMM relayed this information in real time to the C^2 node which confirmed the target ID and assigned an orbiting F-15 equipped with Small Diameter Bomb (Increment 2) weapons to strike the moving target. The OMM ground station provided the F-15 with continuous updates of the target position via a reconfurable networking waveform. When the F-15 was in the launch basket, it released the SDB-2 on the target. The target updates were also relayed to the SDB-2 as it was in flight, so it could adjust its trajectory and keep the weapon within range until its internal seeker took over for the terminal guidance phase. The moving target was destroyed and the F-15 reported BHA and sent an image of the target, which completed the experiment.

Communications

All XML tactical data was exchanged using Publish/Subscribe communication services. Participants included:

- Two virtual Helicopter simulations (Mesa)
- Helicoptors (Philidelphia)
- UAV (St. Louis)
- F-15E (St. Louis)
- Small Diameter Bomb (St. Charles)
- Tactical Mission Computer System (TMCS) (Mesa)
- JEBC2 Command and Control (C^2) services node (Mesa)
- JEBC2 Warfighter Machine Interfaces (WMIs) (Mesa, St. Louis and Palmdale)
- Proxy Guardian Agent (PGA) (St. Louis)

as shown on Figure 15.

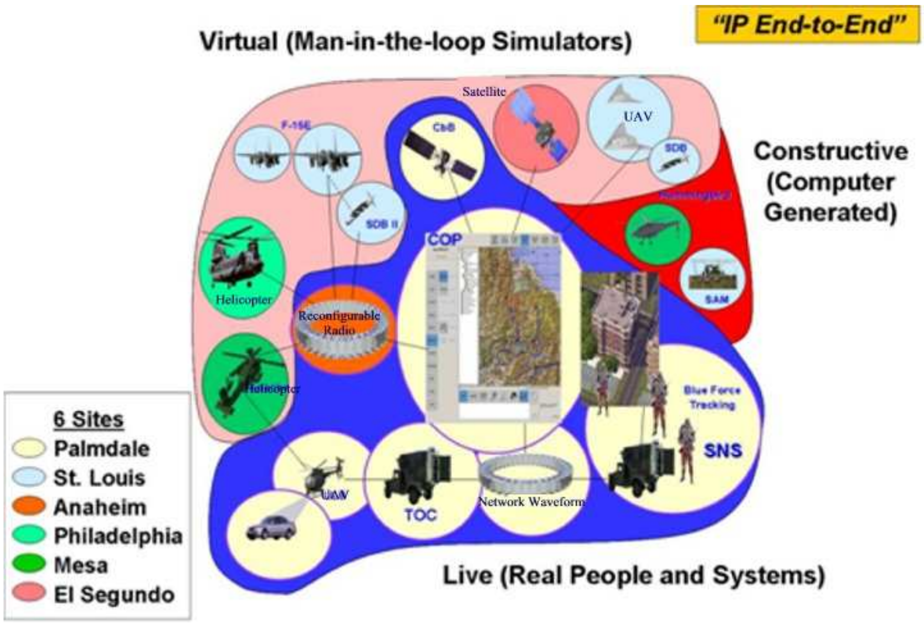


Figure 15 ENCO05 Participants

The helicopter was represented in XML by the Tactical Mission Computer System (TMCS). The TCMS converted the helicopters's DIS entity state PDUs into XML entity reports. The TMCS also handled all XML tactical data communication for the automated blue forces it simulated including UAV. The C^2 services host generated all tasks and mission assignments and maintained the Common Operating Picture (COP) database.

The XML Discovery Service played a significant role in identifying all the publishers and subscribers associated with a given topic. In the case of XML publish /subscribe communication, subscribers could only see the messages from publishers registered with the same attribute values as the subscriber.

For the 2005 experiment, there were essentially two tactical networks, the CoT network and the XML network. Experiment participants were expected to support one of these two tactical networks. Figure 16 showed the organization of the two tactical networks from a CoT perspective. The diagram represents virtual network connectivity. There were six total nodes connected to the Cursor on Target network. To join the two dissimilar tactical networks, a Proxy Guardian Agent (PGA) was connected to the XML network to provide the interoperability between the networks. In order to construct the virtual CoT network, multiple physical networks needed to be brought together. The diagram shown in Figure 16 represents how the various CoT participants were connected in the simulation environment.

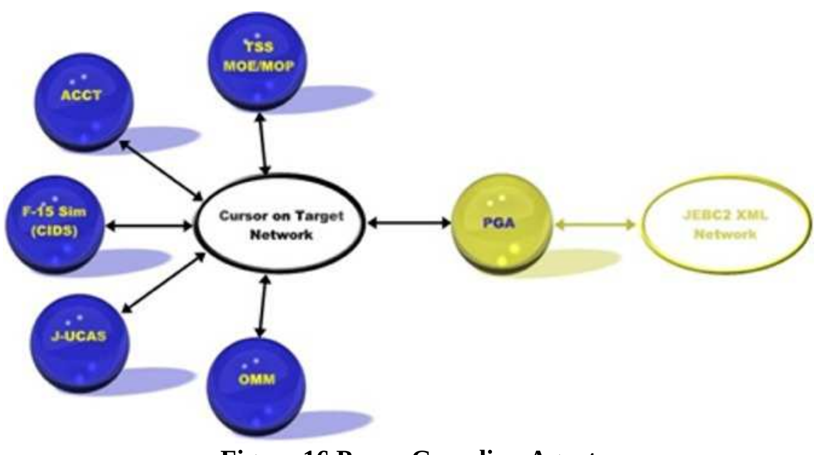


Figure 16 Proxy Guardian Agent

Systems on the Wide Area Network (WAN) could communicate with the network waveform participants (or in this case the F-15's). Since the F-15's were communicating using one type of messages, when things like track messages needed to be published to all demo participants, the AOC (Air Operations Center) would publish to the CoT Router, which would in turn uplink the data to the aircraft using User Datagram Protocol (UDP) messages. In other cases, when a mission needed to be assigned to a specific aircraft, the AOC would open a TCP connection directly with each aircraft to transfer the information. The important point being made here is that the communications worked for both TCP and UDP style communication.

LabNet

The NCO Network was set up among eight sites using a virtual private network. An ATM (Asynchronous Transfer Mode) network was used as the backbone that allowed each of the sites to be tied together. A hub and spoke configuration was utilized to keep the network manageable with St. Louis serving as the hub as shown on Figure 17.

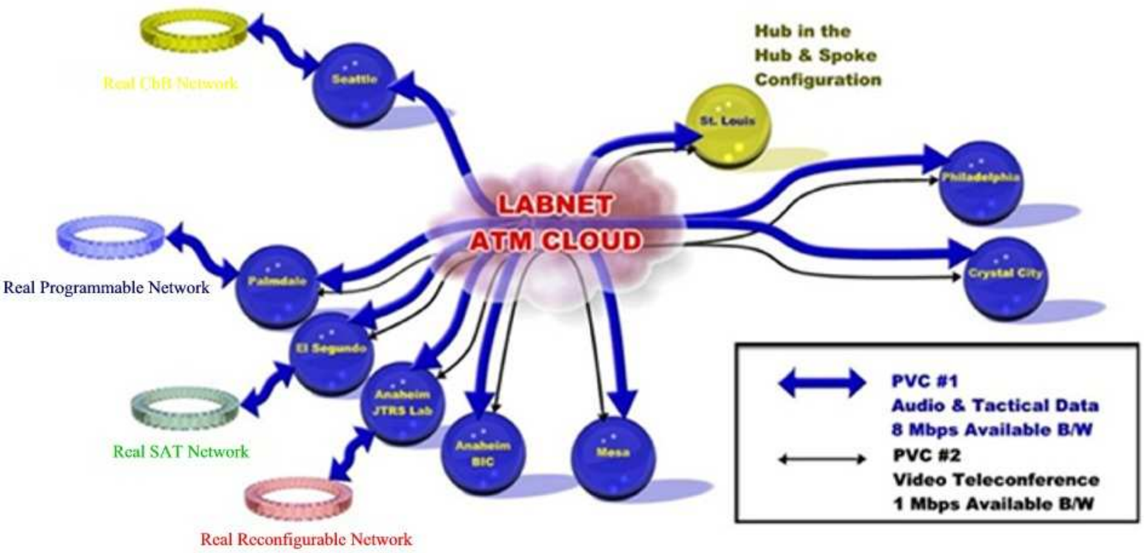


Figure 17 Labnet Connectivity

For this type of experiment, it is important to share the observable network characteristics. During the experiment, a constant ping test was conducted to monitor the health and status of the networks. During this time, it was noted that round trip times were in the 500-800 msec range for networking waveform. Similarly, satellite round trip times were in the 1000-1300 mse**c** range. This is very important to the application developers as they should take these types of latencies into account when developing their applications. In some cases, some of the applications being used for the experiment assumed latencies that were much more typical of a Local Area Network (LAN). As such, there were often problems connecting some applications over these networks. To prove that it was not a network configuration or NCO Router issue, applications such as Internet Explorer were used to test the connections over both satellite and networking waveform. IE performed very reliably and served as a good connectivity test for TCP.

While there was some additional latency contributed by Labnet, the typical round trip times observed without satellite or the networking waveform in the loop was on the order of 35-50 msec. By and far, the majority of the latency observed came from the link effects imposed by the real waveform and satellite hardware.

The chance to test applications in a distributed environment such as this with real hardware in the loop without having to pay for and coordinate live flights is a huge benefit to The Boeing Company. This now means that applications intended for use in these relatively high latency environments (at least when compared to a LAN) can be tested for performance. More importantly, these performance tests can be repeated many times which allows the entire system to be debugged from end-to-end in a controlled lab setting.

The primary role of the Proxy Guardian Agent (PGA) in the experiment was to convert tactical data messages between the CoT and XML protocols. The PGA was designed to act as a proxy for entities residing on dissimilar networks.

In this experiment, the Proxy Guardian Agent translated between two message sets – JEBC2 XML and CoT XML. Table 1shows the data flow for each message type used in the experiment. Translators existed for several more data flows, but only those used in the experiment are shown below.

Table 1: Message Types & Data Flow

Native XML Messages		
JEBC2 XML →	**Base Object →**	**Cursor on Target**
EntityListData	Track	Fused Sensor Report
Command	Mission	Mission Assignment
SensorReport	Image	CoT Image
Native CoT Messages		
Cursor on Target →	**Base Object →**	**JEBC2 XML**
Raw Sensor Report	Track	EntityReport
Ownship Report	Track	EntityReport
Imagery	Image	SensorReport
BHA	BHA	Notification
Acknowledge (WILCO, etc)	Acknowledgement	Notification

Cursor on Target[xiii] is a message exchange standard defined by MITRE to support the exchange of tactical military information. All CoT messages are just basic XML files. However their structure enables considerable flexibility in their use. Essentially, every CoT message is an 'Event' message, so a track, a mission assignment, an image, etc. are all events.

CoT only defines the message format. It does not define the transportation medium or methodology. Thus the developer is given free reign on how to exchange messages (with some reservations). In addition, MITRE provided an application called the CoT Router which can be used to help in the distribution of CoT messages. The CoT Router allows multiple systems or applications to post a subscription which defines where messages are to be sent. In addition, the CoT Router supports the filtering of messages based off of location. Additional filtering can be defined in the subscription through the use of predefined methods and regular expressions. The CoT Router is a Perl based application but it has been packaged into a single Windows based executable.

Operations

The operations involved many platforms to provide a thread of functionality for the simulation as shown on Figure 18.

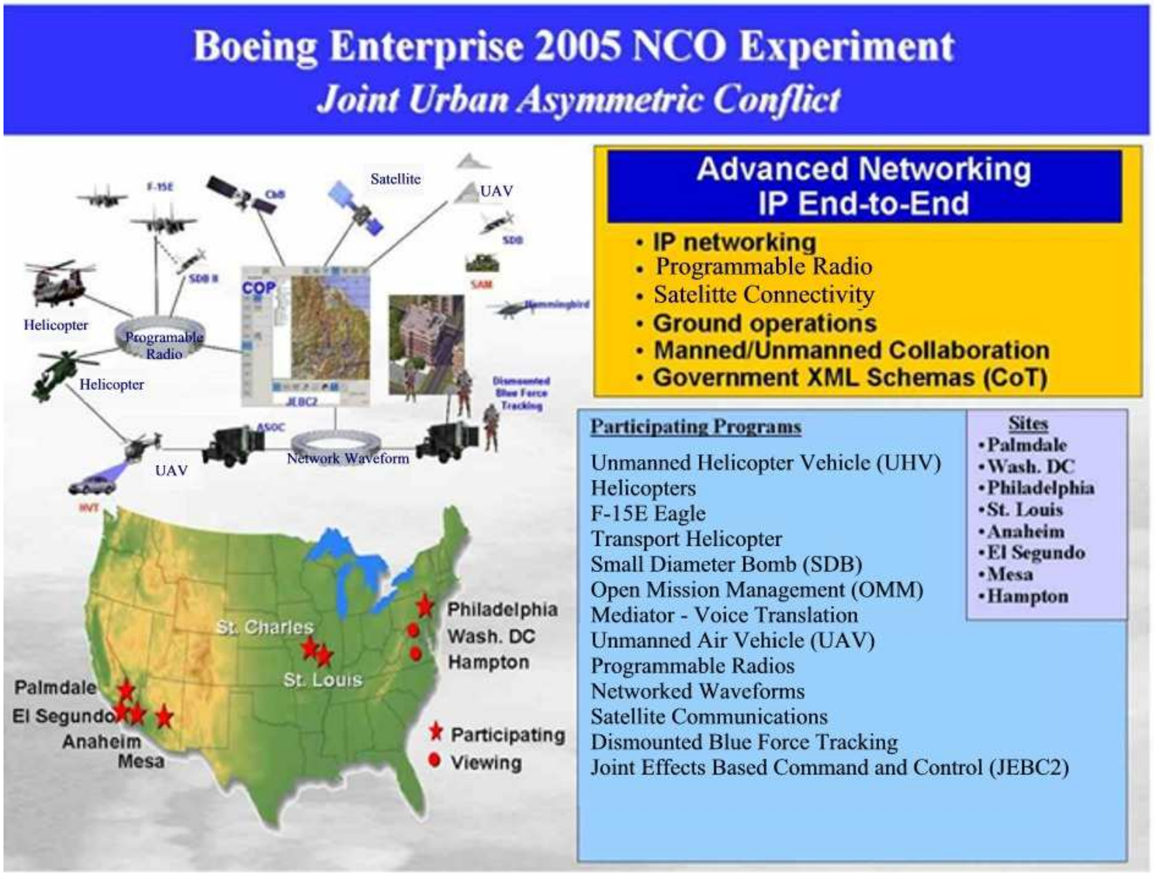


Figure 18 ENCO 05

DIS

The DIS protocol was the primary interface through which simulations/systems, worked together in a collaborative simulated environment, exchanged information. The DIS interface is defined by the following IEEE standards:

- IEEE Standard for Distributed Interactive Simulation-Application Protocols (IEEE Std 1278.1-1995)

- IEEE Standard for Distributed Interactive Simulation-Application Protocols (IEEE Std 1278.1a-1998)

Communication over a DIS network generally consists of a series of UDP packets. While not limited to Ethernet or IP, this is the medium most often used and the medium that was chosen for the NCO experiment. Further, DIS is capable of supporting peer-to-peer, broadcast, and multicast modes of communication. For the NCO experiment, multicast was utilized in order to minimize the volume of network traffic during the experiment.

DIS uses the term Protocol Data Unit (PDU) to define the format of packets sent over the network. All PDUs formats are defined by IEEE Std. 1278 and define the bit and byte alignment for all of the fields in the message. The following subsections briefly describe each of the DIS PDUs utilized for the experiment and their general purpose.

<u>Entity State PDU</u>

This message was used to report the location, velocity, and orientation of entities operating within the simulated environment so that they may be positioned and rendered properly in relation to participating entities being simulated by other distributed applications. This message also includes a definition of the body type so that the object can be properly identified. This message was generally reported at a variable rate depending on the dynamics of body motion. Generally, the more dynamic the object was, the more often the Entity State needed to be updated and transmitted.

For the NCO experiment, each application simulating an entity within the simulated environment was responsible for maintaining and reporting the position of their respective objects.

<u>Fire PDU</u>

The Fire PDU was used to report the release of all munitions of some type within the simulated environment. This message contains the entity that released the munition, the point of release, the type of munition, the velocity of the munition, and the targeted entity, if known.

For the NCO experiment, this message was used to report the release of the various munitions. Whenever munitions was released, the generating simulation would report Entity State PDUs for the munition until its target had been struck at which point the Entity State PDUs would stop being reported and a Detonation PDU would be sent as notification.

Applications like GenView and Clouseau used this information to depict the location of the munition within each of their respective displays. This allowed the observer to watch the weapon release and impact take place.

<u>Detonation PDU</u>

The Detonation PDU was used to report the impact and subsequent explosion of munitions. This message identifies where the detonation took place and the entity (if any) that was struck.

For the NCO experiment, this message was used to report where the munitions struck the surface. For the F-15 and J-UCAS simulators, the target location was taken from the CoT messages that were used to perform the mission assignment. For the Helicopter and simulated UAV, the target coordinates were taken from simulated on-board sensors. These sensors were used to detect the location of the mortar and the convoy.

<u>Emissions PDU</u>

The Emissions PDU was used to report entities that are emitting some type of RF. This allows other simulators to exercise their simulated sensors and determine if the respective simulated asset is able to detect the emitting entity based on the location and orientation of the aircraft in relation to the emitter.

For the NCO experiment, this message was used to detect the location of the SAM site that the UAV platform attacked. In addition, the F-15's also exercised their simulated on-board sensors to detect the SAM site as well. Both UAV and the F-15's reported the location of the SAM site to the COP via CoT track report messages. This information was fed through the network back to the JEBC2 system where fusion was performed on the track reports. Subsequently, the result of the fusion was transmitted back out to all demo participants so that everyone had the same picture of the battlefield environment.

Facilities

The facilities included for all the simulations were in several cities as shown on Figure 19.

Figure 19 ENCO Simulators and Sites

The facility in St. Louis is shown on Figure 20.

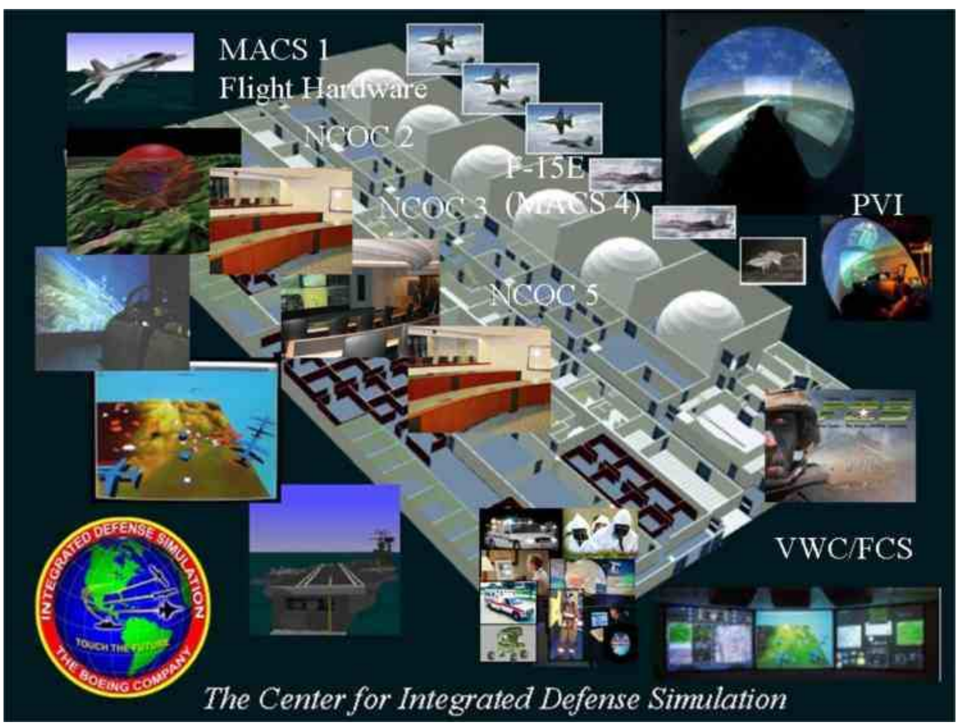


Figure 20 CIDS - St. Louis, MO

A typical display from the St. Louis simulator is included in Figure 21.

Figure 21 St. Louis Simulators

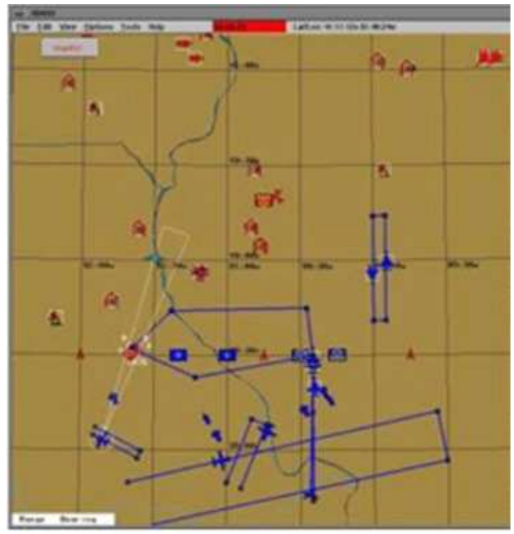
Palmdale also supported the Enterprise Network Centric Operations Experiment. The key to the success of this demonstration was the ability to connect multiple fielded systems/programs into a common NCO environment. This experiment required the integration of live assets into the experiment environment to provide a true sense of realism. The experiment facilitated the display of genuine advancements made by the NCO development community as a whole. All information flow was in real-time with multiple live streaming video feeds coming from Palmdale and being displayed at all 2005 Enterprise NCO Experiment locations.

This year's experiment required the Palmdale team to integrate multiple hardware systems/programs and to coordinate the precise movement of key actors in the experiment battlefield environment. Key features of the experiment included live (see Figure 22) and real-time networked assets performing network centric operational capabilities using mature technologies. This demonstrated to the customer that long term NCO visions were being realized, and that the Boeing solution is not only achievable, but fully compatible in an NCO environment.

Figure 22 Palmdale Facility

E. Constructive Simulation

The Interactive Warfare Simulation (IWARS) is a fully operational tool which provides a modeling and system simulation to support analysis of the effects that sensor performance, signature, weapon, and tactics have on overall weapon system performance in a realistic battle environment including aircraft, ships, missiles, and other fixed or moving objects as well as associated sensor suites and weapon load outs. It has been approved for export with approved data or used at different levels of classification in US facilities. Users interactively control team assets within the graphical environment. IWARS was used to provide timely configuration, scenario, and timing decisions early in the development and an integration stage of the NCO demonstration. In addition, IWARS allowed tactical utility and design feature interaction to be evaluated in an integrated force on force "real world" environment. IWARS was chosen as the constructive model for the Network Centric Operations (NCO) Demonstration to provide the environment, to stimulate the various sensor suites, and to provide sensor track data to the ISR and AWACS off-site data fusion models. Though IWARS did not provide LINK 16 data to the network during the simulation, it was fully capable of doing so.



Results

The 2005 Enterprise NCO Experiment successfully met and demonstrated all planned objectives.

- Persistent Shared Awareness at all Levels
- Machine-to-machine network interoperability
- Dismounted Soldier Tracking and Situational Awareness
- Real-time imagery and threat updates with distributed data fusion

The heterogeneous IP-based network was extremely effective at routing the data required for maintaining a Common Operational Picture (COP) for each tactical operator and commander. This included the forwarding of position data for individual dismounted soldiers to all C^2 and Close Air Support (CAS) platforms. Nodes connected to the radios, waveforms, satellite, Connexion by Boeing (CbB), or LabNet networks were all able to exchange information without modification to their existing software. In addition, message-level translation technology allowed interoperability between a C^2 workstation that utilized a XML based schema format and a platform that utilized Cursor-on-Target schemas for seamless machine-to-machine interoperability.

- Speed of Command
- High Bandwidth C^2 on the move with global reach
- Reduced decision time via information sharing and collaboration tools

Two live Humvees with waveform network capability provided commanders in the experiment to monitor and command their squads while maintaining a high bandwidth connection to the Global Information Grid (GiG) to for high situational awareness. The Mediator system was an example of how a dismounted language translation technology could be coupled with a high bandwidth reach back connection to an assessment center to provide real-time intelligence to the field and reduce the decision time for modifying courses of action for troops in the field.

- Dynamic Employment
- Rapidly detect, assess and destroy multiple targets

- Multi-mission, multi-role manned-unmanned vehicle teaming
- Drive execution authority to the lowest levels

Pop-up targets were quickly reported on the network to the appropriate C^2 authority. Platforms immediately saw the threats on their SA pictures and C^2 dispatched the appropriate weapon system to prosecute the threat. All exchanges of SA and C^2 data were accomplished through digital machine-to-machine interfaces. In the case of the pop-up mortar and convoy attacks, the Helicopter demonstrated teaming with the unmanned helicopter (UHV) which it used as both a sensor and weapon fire platform. Because all C^2 and platforms nodes had access to the same SA data on their common operational pictures, mission objectives were clear and execution orders were granted by a single commander using WMI as shown on Figure 24.

Figure 24 WMI Display

The success of the 2005 Enterprise NCO Experiment was possible because of the efforts of many people from multiple Boeing locations and a wide array of disciplines.

II. Distributed Live, Virtual and Constructive Modeling and Simulation to Support System Engineering Rapid Prototyping, Development and Testing

Boeing has used the concepts of rapid prototyping to refine the requirements for years with the use of design advisory groups (DAG)s for example. The concept works to have the operators see and try out new concepts as was discussed. Recently, the uses of advanced weapons and sensors have been used to support urban operations. There are several locations where the military has built Military Operations on Urban Terrain (MOUT)[xiv]. Close Air Support (CAS) of ground forces or precision targeting remains challenging, particularly in urban terrain. CAS in general, and urban CAS in specific, requires practice to achieve effectiveness. At the same time, opportunities to develop new tactics, test new procedures, and try out new equipment or capabilities in a realistic urban ops environment are very limited. Very few test and training urban environments offer realistic Urban Ops conditions for all players. Most MOUT training areas are small scale—many times being only a group of cargo containers stacked 2-3 high. Others are of better fidelity, but are still small and low (2-3 stories max) when compared to Baghdad, Fallujah, or other urban areas-- adequate for ground troop training, but not large enough for realistic aircrew training. Flight crews have access to some weapons ranges with urban-like targets, but these suffer from many of the same problems: too small, too low, and not realistic enough to challenge the aircrews. Additionally, most well-developed urban operations ranges are expensive to build and maintain, particularly those used for ground training. As a result, most ranges don't allow the use of even practice ordnance on these facilities, much less real ordnance. As an experiment, Boeing built two virtual MOUT-type areas with moving ground targets, so we could look at the operations around the southern California area along with operations in two replica southwest Asia areas as shown in Figure 25.

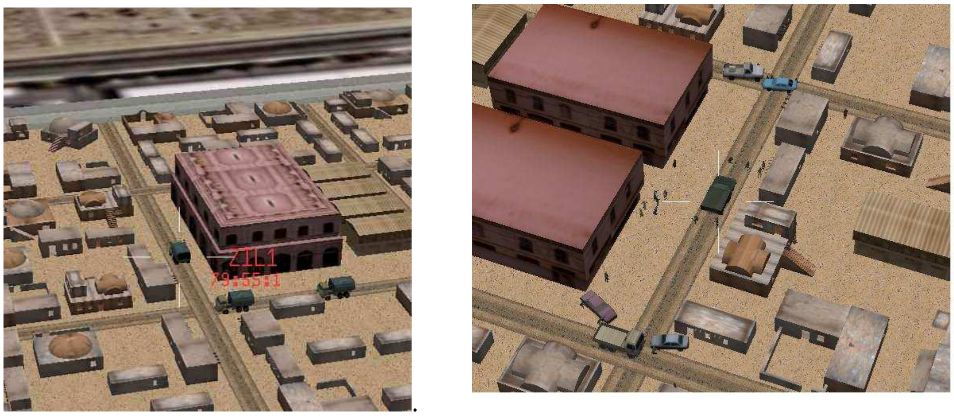


Figure 25 Urban Combat

By using these types of areas, we have started to investigate the timing, communications effects and weapons effects used in Close Air Support in Urban areas. Recent studies have shown a significant reduction in talk-on time for a Joint Tactical Air Controller (JTAC) to fighter pilots as well as a significant reduction in the time from check-in to weapon release.

III. Conclusions

By applying the techniques described for the hardware, simulation and computer assets, an integrated Live-Virtual-Constructive (LVC) environment was created to provide the ability to "test concepts like as we fight", which has been a multi-service goal for nearly a decade. The vision of a seamless network of live participants, virtual simulations, and constructive models formed an environment for the military to do research, rehearse, and assess courses of action has been slow to materialize due to a variety of technical, cost, and policy challenges. However, recent advances in affordable technologies, and the emphasis on transforming force structure and operating relationships, has created a window of opportunity for significant progress towards this integrated LVC environment.

The NCO Thrust Waveform was used to extend the IP-based networks to the tactical edge and enable a demonstration of a vision of C^2 for the Army on the Move. We also developed an IP routing technique that created a distributed live-virtual-constructive simulation infrastructure that allowed real communication hardware to be placed in the loop for any two communicating platforms no matter where those platforms or the communication hardware happened to be located. Finally, the Proxy Guardian Agent technology was further enhanced to handle the seamless translation of message data between C^2 nodes and platforms using different XML schema protocols.

IV. Future Work

If the live and virtual assets are in the same proximity, any lags in the algorithms would be obvious and objectionable. To counteract this issue, the use of a global GPS satellite timer would allow all simulators to use a common clock and get a much better idea of the time when the data was recorded, so the use of sinusoidal interpolation and extrapolation could be used to provide a better approximation of the position of all entities. The use of a sinusoidal predictor will also provide a better approximation of extrapolated positions. Another alternative is to provide an estimation of the aircraft dynamics between update intervals that would provide an estimate of the aircraft dynamics.[xv]

[i] http://en.wikipedia.org/wiki/Image:Systems_Engineering_Process_II.gif, INCOSE Systems Engineering VEE, SEOR, George Mason University. Retrieved on 2007-05-26.
[ii] Red Flag - 414 Combat Training Squadron (CTS), http://www.nellis.af.mil/red_flag/, 2005.
[iii] Training Systems Delivered , The Bowing News, 2003.
[iv] AIAA-2004-5148, "The History and Future Of Military Flight Simulators", Bezdek, William, Mays, Dixie, & Powell, Rayner, AIAA Modeling and Simulation Conference, August 2004.
[v] Distributed Mission Trainers, Boeing News, St. Louis, August 4, 2003.
[vi] Link-16, http://en.wikipedia.org/wiki/Link_16, 2006.
[vii] Red Flag exercises, held periodically at Nellis Air Force Base since 1975, are very realistic aerial war games http://www.dreamlandresort.com/info/nellis.html, 2006.
[viii] AIAA-2005-6499, "Providing DIS Entities for a Flight Test Vehicle", W. Bezdek and J. Maleport, 2005.
[ix] Distributed Interactive Simulations (DIS), IEEE Standard for Information Technology - Protocols for Distributed Interactive Simulation Applications, 12 May 1993.
[x] BAT UAV, http://www.spyplanes.com/bat3.html, 2006.
[xi] AIAA-2006-2116, "Distributed Real Time Simulation using DIS and XML", Bezdek, William J, Maleport Joel, Olshan, Robert Z., AIAA Modeling and Simulation Conference,August 2006
[xii] http://www.military-information-technology.com/print_article.cfm?DocID=596. Military Information Technology, William Miller, 2004.
[xiii] Cursor on Target, MITRE Corp, http://www.mitre.org/news/releases/06/afcea_07_14_2006.html, 2006.
[xiv] MOUT Facility, http://www.jrtc-polk.army.mil/JRTCExercise/MOUT.HTM, 2006.
[xv] AIAA-1993-3552, Dynamic Simulation Fidelity Improvement using Transfer Function State Extrapolation, Bezdek, William J. & Moody, Larry A., AIAA Modeling and Simulation Conference, August 1993.