Integrated Live Virtual Constructive Technologies Applied to Tactical Aviation Training

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ABSTRACT

Various Department of Defense (DoD) organizations have recognized shortfalls in training opportunities and assets to meet operational demand. The complexity of current and future weapons systems demand concurrency training in an environment representative of realistic battlefield conditions, yet the DoD can ill afford to provide this level of training at the desired frequency. Aviation fuel price escalation and range space limitations are exacerbating the training dilemma. Traditional training applications include the following discrete categories: Live, training on actual platform hardware; Virtual, training on manned simulations; and Constructive, training with computer generated simulations of battlefield conditions.

With the advent of interoperable training capability, such as the Air Force's Distributed Mission Operations (DMO), the ability exists to link local or remote training systems over a local or wide area network for the purpose of training in a team environment. The DMO network has the capability to greatly enhance the live training domain by supplying a vast operational environment composed of virtual and constructive red/blue forces. The integration of live platforms onto the DMO network, however, has unforeseen training challenges that need to be addressed.

This paper discusses the research performed and the challenges encountered when an integrated LVC experiment was performed with a tactical aviation platform. In 2007, an airborne F-15E aircraft was integrated with a ground-based manned F-15E training system acting as a wingman and a constructive environment generating hostile aircraft. We also discuss the safety of flight considerations, the transfer of training issues encountered and the solutions chosen during the development of this effort. This paper addresses training capability and capacity increases that can be gained while reducing life cycle costs of on-platform training and lastly, areas requiring further research. As research is ongoing, additional results from this year's effort may be available for presentation.

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INTRODUCTION

Traditional air combat tactical pilot training consists of ground-based training, simulation-based, and live flight training to teach avionics usage and cognitive flying skills. While ground based training can be a very economical method of pilot training, it is not robust enough to cover critical dynamic skills. Live flight training can provide this enhanced training capability, but can be very costly in nature. For example, in order to perform a training sortie indicative of an operational sortie, a compliment of aircraft must be fielded to represent both blue forces and red forces. Mission roles and routes must be planned and coordinated. Fuel must be allocated, flight schedules deconflicted, and maintenance completed to allow asset readiness. Availability of resources, allocation and scheduling of integrated air defense assets on Air Combat Maneuvering Instrumentation (ACMI) ranges limits training options. Inclusion of command and control nodes such as Airborne Warning and Control System (AWACS) adds another dimension to the complexities of coordinating a true-to-operation training sortie. The costs of pulling together these assets can be in the hundreds of thousands of dollars per event and are both cost prohibitive and time consuming. The training or readiness value added for highly skilled pilots to fly in a red air role can be questioned. Additionally, use of the assets adds to platform wear, requiring additional maintenance and accelerating aging of the air fleet.

In recent years, training capabilities have moved beyond cognitive skills training to tactical operations training through ground-based training devices. This is evidenced by the growth of squadron-based pilot training systems that interoperate in a distributed training environment, such as the US Air Force's Distributed Mission Operations (DMO) environment and the US Navy's Naval Aviation Simulation Master Plan (NASMP) environment. These environments dictate that systems must fully represent the weapons platforms in an operational environment to include authenticated avionics and sensor models, air threats, integrated air defense systems, and command and control nodes. These systems must interconnect from base to base through government operated networks via standards-based protocols. While these systems are in full operational use for ground-based training and limited use for live experiments & validation, their potential has yet to be realized for inclusion in live training events. This paper addresses an experiment performed to integrate a live tactical aviation platform with a ground-based training system and the virtual and constructive environment required to support training.

The terminology Live, Virtual Constructive, or LVC, is common parlance in today's Department of Defense services. While LVC may be common terminology, it has many connotations to many people, depending on the application. For some it may mean a persistent network to perform test, experimentation, and analysis. For others it is providing the interconnection of systems and networks to various assets for the purpose of performing training. And for others, it is a means to perform modeling and simulation in the experimentation and design phase in the weapon system life cycle. For the purposes of this paper, we refer to LVC as the integration of Live aviation platforms in the Virtual and Constructive domains for the purpose of training.

TACTICAL AIRCRAFT TRAINING CHALLENGES

Fourth and Fifth Generation Aircraft

Today's fighter aircraft are characterized as fourth or fifth generation aircraft. Aircraft classified as fourth generation jet fighters are those in service approximately from 1980–2010. Fourth generation aircraft are characterized by advanced avionics and multi-role mission capable, with a focus on maneuverability.

Notable fourth generation aircraft	
F-15C Eagle	F/A-18A-D Hornet
F-15E Strike Eagle	F/A-18 E/F Super Hornet
F-16 Block 30 – 60 Falcon	JAS-39 Gripen
Tornado	Su-27, Su-30
MiG-29, MiG-31	Typhoon

Fifth generation fighters are characterized by advanced integrated avionics systems that provide integrated situational awareness (SA) and the use of low observable technology.

Fifth Generation Aircraft	
F-22A Raptor	F-35 Lightning II

Avionics & Weapons Complexities

What all of these aircraft have in common are complex avionics systems and weapons delivery capability. While fifth generation aircraft have the luxury of integrated SA, forth generation aircraft have discrete information displays that require the pilot to perform mental SA. Even with integrated SA, there are underlying layers of information that must be interpreted and analyzed by the pilot while monitoring secondary information and performing the mission. The F-22A alone has six displays, of which one is the primary display and three are secondary displays[1]. Hands on Throttle and Stick (HOTAS) are designed to allow the pilot to operate the displays, avionics, and weapons by pushing buttons and switches on the grips without releasing the stick and throttle. The HOTAS controls a myriad of time-critical functions including display formats, sensor controls, and weapons targeting and release within the aircraft, all of which must be recalled by the operator during high stress situations.

Current military doctrine calls for the use of precision guided stand-off weapons. A Small Diameter Bomb uses the Global Positioning System to fly to the target at a standoff range of more than 60 nautical miles. [2] The AGM-154 Joint Standoff Weapon is a high altitude launch weapon with a range of more than 120 nm when powered. Current upgrades bring this range up to 300 nm for precision attacks.[3] The Standoff Land Attack Missile – Extended Range (SLAM-ER) provides surgical strike capability against high-value, fixed land targets, ships in port, or at sea. The missile is launched from a distance beyond 150 nautical miles, and flies a subsonic flight, navigating by an INS/GPS navigation system.[4] Some current and certainly future stand-off weapons will exceed the footprint of training ranges.

Training Range Issues & Complexities

The DoD operates and maintains a large inventory of test and training ranges spanning air, sea, and ground environments (ref. Figure 1[5]). These ranges play a critical role in preparing our military forces for wartime deployment. Other industry parties are playing a major role in the development and support of equipment that will help enable I-LVC on these ranges.

While these ranges may be some of the most advanced ranges in the world, the Government Accountability Office (GAO) found "that military training ranges … lack necessary upgrades to meet current training needs, a condition that, in turn, adversely affects training activities and jeopardizes the safety of military personnel using them."[6] The report states that electronic warfare ranges lack a capability to portray a dense, realistic, current threat and target environment, insufficient time-sensitive

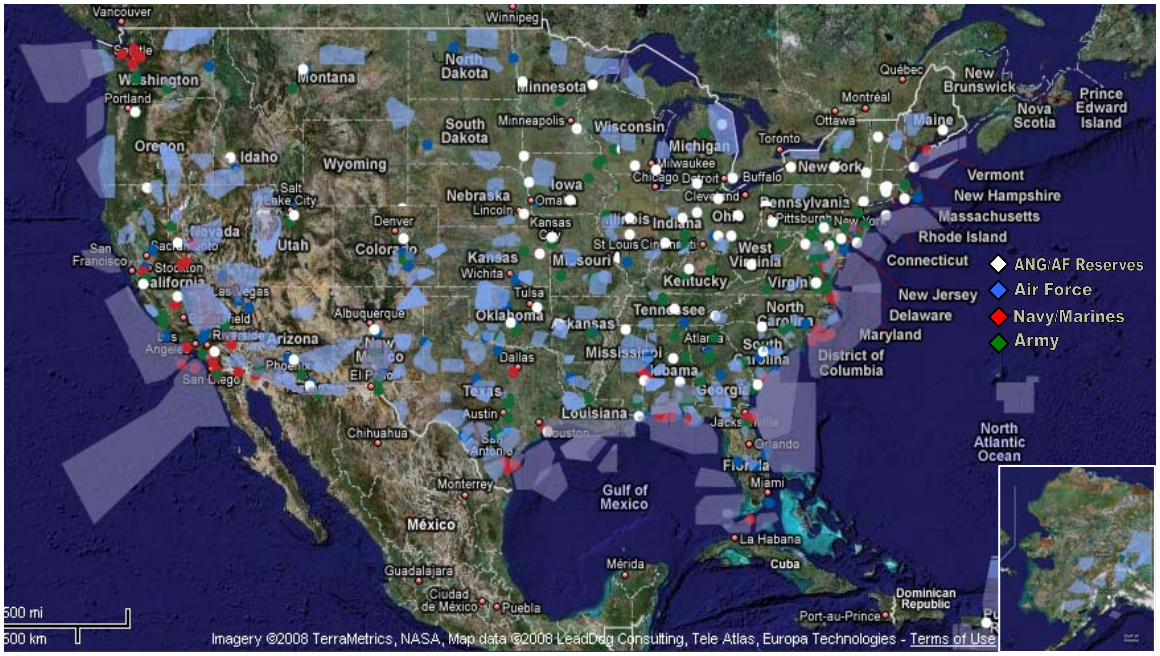

Figure 1 – Military Operation Areas & Special Use Airspace

moving targets, and inadequate instrumented feedback and scoring systems, a finding that has been validated by our research. Additionally, ranges are facing encroachment pressures, such as private development adjacent to ranges, restrictions imposed by environmental regulation, and growing competition for airspace and frequency spectrum, all of which are impeding the ability to conduct tactical air operations training, limiting the use of active electromagnetic emissions, and train tactical weapons employment ranges in realistic environments.[7]

Recognized Training Shortfalls

The shortfalls in training arise in maintaining proficiency with the operation of the complex avionics and weapons of fourth and fifth generation aircraft. While tactical flying skills are ingrained in pilots, the amount of display pages, sensor and weapons controls can be overwhelming. The operation of these systems must be second hand in nature to the operator. To exacerbate the situation, our forces fight in multi-ship, multi-force operations, allocating and sharing sensor data amongst the platforms. Pilots must be cognizant of both current and future positions and locations of all forces in the battlefield to avoid mid-air collisions and fratricide.

Deployed pilot proficiency and readiness in mission critical skills is decreasing due to Operational Tempo. Data from Operation Iraqi Freedom and Operation Enduring Freedom has shown that pilots spend airborne time performing combat air patrols and circling areas of responsibility.[8] This does not allow for much training in mission critical skills such as basic fighter maneuvers, combat tactics, and weapons employment —all of which are deteriorating due to lack of available time to perform skill training in theater. The DoD has chosen the mantra "Train like we Fight", however, given the expense of launching live weapons and complexities of missions representing battlefield conditions, pilots infrequently get an opportunity to train as they would fight.

An approach to solving the above limitations and deficiencies is the incorporation/integration of live platform training into the vastly successful implementation of distributed mission training. LVC has the ability to bring forward a complex battlefield with a dense, realistic, current threat environment, providing the ability for aircraft to collaborate, sort, target and launch on reactive targets. Reuse of existing recording and after-action review capability can provide high-fidelity, correlated, synchronized scoring and feedback for training operations. Lastly, depending on the implementation, this capability can be used both pre-deployment and deployed in theater.

INTEROPERABLE TRAINING NETWORKS

Training Network Capability

The Combat Air Force Distributed Mission Operations Network (DMON) is a persistent network that provides for the interoperation of various virtual and constructive simulation and training devices. It is utilized for both distributed squadron-based training exercises and larger exercise events (ref. Figure 2).

Figure 2 – Example CAF DMO Interoperability Event

Other popular government networks include Joint Training and Experimentation Network, the backbone for the Joint National Training Capability, and the Air Reserve Component Network (ARCNet). All of these networks carry entity positional information, weapons information, signal (emissions) information, communications information (radio comms) and command and control information (e.g. Tactical Digital Information Link-Joint, a.k.a. TADIL-J) that can be utilized by a live tactical aviation platform for training.

Live Tactical Aviation Platform Connectivity into Training Networks

There are various levels that tactical aviation platforms can be tied into or integrated with a large terrestrial based training network. Several levels of I-LVC are discussed below, each with increasing level of complexity.

Level One – ACMI Connectivity

This level entails a uni-directional connection of a live platform to the training network. A typical instantiation would include aircraft positional data being reported onto the terrestrial training network via an ACMI ground station. Additional connections from the live platform can include uni-directional tactical datalink messaging via a datalink-to-network bridge (e.g. Link 16-to-DIS) and bi-directional voice communications. This level has value for ground-based training, but low value for live airborne training (i.e. – no feedback from the ground network to live platform).

Level Two – Command & Control Connectivity

The second level of connectivity builds upon level one with the addition of bi-directional tactical datalink messaging. This methodology allows command and control data from the terrestrial network to be reported to the airborne platform. This level has high value for ground-based training and median value for live airborne training. While this level does provide some ability to exercise threat avoidance, it lacks the ability for the live platform operator to perform sensor acquisition and targeting and exercise weapons deployment on virtual and constructive forces.

Level Three – DMO Connectivity

The third level provides the most effective methodology in both training effectiveness and live training cost efficiency. Again building upon the previous two levels, level three entails bridging pertinent training data on the terrestrial network over a datalink to the airborne platform for training purposes. This level entails installing simulation systems, either on-board or via external carriage, that simulate/stimulate sensors and weapons to provide the operator the ability to manage threat avoidance, perform sensor acquisition and targeting, and exercise weapons deployment in flight. Additionally, the platform must report precise position/orientation information, emissions, and weapons data to the terrestrial DMO network to participate within the virtual and constructive environment. One of the most straight forward methods to implement this is for the live platform to replicate the DIS protocol.

Live Tactical Aircraft Integration into the Virtual and Constructive Domain

To achieve level three connectivity of a tactical aircraft into the distributed mission training construct, a challenge exists to find a common architectural thread amongst live platforms. In order to prevent stove-piped solutions, which will lead to disparate, costly approaches to an integrated LVC environment, a standardized approach must be targeted. US Joint Forces Command has begun an initiative to address LVC architectures and interoperability approaches.[9] While they are addressing interoperability at the communications level, a further study needs to be performed on platform architectures. For example, current day weapons systems operate via a central computer that receives sensor and weapon data via the MIL-STD-1553B avionics bus (ref. Figure 3). The central computer typically assembles, manages, correlates, tracks, and displays data received from the sensors and weapons for the operator, both on and off-platform. In order for training data to be injected into the central computer, access must be provided to the 1553 bus either via an existing bus terminal or an additional bus remote terminal added specifically for training. However, the 1553 bus has timing and bandwidth constraints. These constraints must be considered so as to allow normal operation of the platform avionics while not exceeding the capability of the bus and computer. In addition, the central computer may have processing limitations, further exacerbating the functional allocation and decomposition of the architecture.

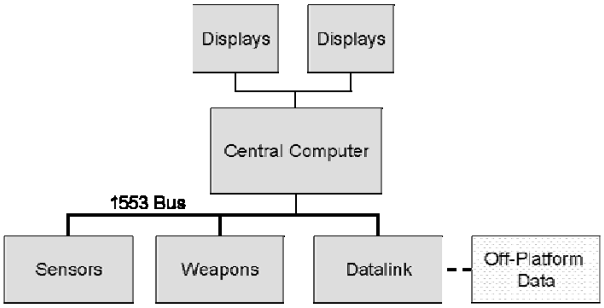

Figure 3 – Typical Integrated Avionics Suite

Several approaches are fielded or under development for the incorporation of interoperable embedded training in the live platform. Most platforms have some level of embedded training, be it embedded weapons simulation, external mounted weapons emulation, or an embedded training processor.

For example, the AH-64 Apache Longbow has the Tactical Engagement Simulation System (TESS). It is comprised of an aircraft system and an operational environment opposing forces system that provides player-to-player communications, decentralized engagement adjudication, and Real Time Casualty Assessment. TESS uses geometric pairing for all Longbow weapons including hellfire, rockets, and 30mm guns.[10] The F-15 and F-16 platforms utilize an externally mounted ACMI pod (internal mount for F/A-18) that provides position/location information and target pairing. The M-311 and M-346 fighter training jets have the Embedded Tactical Simulation capability which allows the avionics to simulate sensors and systems. The US Navy is outfitting the T-45 Goshawk with the Virtual Mission Training System (VMTS) which will provide a synthetic radar training facility to emulate an existing F/A-18 radar system and include capabilities such as a radar warning receiver and air-to-air weapons simulation.[11]

What do all of these systems have in common? The answer is decentralized architectures and proprietary communications protocols. None of these systems take advantage of current distributed/collective mission training capabilities in use within the DoD today.

Considerations/Challenges When Integrating with Training Networks

Embedded or Off-board Computer Generated Forces

In order to provide constructive forces for a live platform, computer generated forces (CGF) must be supplied by either an embedded on-platform or ground-based off-platform system. An on-board capability provides for stand-alone, un-tethered operation. However, the system must be pre-programmed with mission scenarios before flight and will typically remain unmodified during flight. If it is used in a multi-ship, linked system, one CGF must be designated as the master in order to maintain correlation. The utility of an off-platform system is that the system is not duplicated through the fleet of aircraft, scenarios can be modified on the fly as a mission progresses to match pilot proficiency and create uncertainty, correlation is maintained by all platforms subscribing to the CGF, and it requires less computational cycles on-board the platform. The negative to an off-board approach is that it requires additional datalink bandwidth to transmit entity information.

Datalink

To connect an airborne tactical aircraft to a terrestrial network, a digital radio or datalink, and ground station will be required. There are various datalinks in use by the DoD. Parameters to be considered are data protocols, data rates, secure operations accreditation, operational range, frequency allocation, latency, network architecture, determinism, and fielding considerations. Under fielding considerations, one must decide whether to use an existing (e.g. TADIL-J) or new datalink (e.g. Joint Tactical Radio System/Tactical Targeting Network Technology), consider the time to implement on various platforms, and be aware of ground station deployment.

For example, TADIL-J has a nominal operation range, is deployed across a number of fourth and fifth generation tactical platforms (ref Table 1), is secure and deterministic, however, its data rate is low compared to typical training and simulation networks.[12] Design trades will need to be understood on the training capacity versus bandwidth for this datalink. Various modes of operation such as stacked networks or multi-netting can increase the virtual bandwidth of the network. Thus, in it's configuration it can be considered for limited training exercises. Additionally, there are enhancements under way to increase the throughput to support high data-rate applications which will expand the training applicability and capacity.

F-15 C/D Eagle	E-8 JSTARS
F-15E Strike Eagle	E-2C
F-16 Falcon	F/A-18 C/D/E/F Hornet
F-22A Raptor	RC-135 Rivet Joint
E-3 AWACS	

Table 1 – TADIL-J Compatible Aircraft Platforms

Operational Flight Program (OFP)

As previously stated, the Central Computer, which runs the OFP, is the main collection point for sensor systems. Whether sensor simulations are embedded with the Central Computer or contained within an additional avionics processor, the OFP will need to be modified in order to access the data generated by the sensor simulations and send pilot control information to the simulations (e.g. RADAR steering commands). The most effective way to implement LVC algorithms in the OFP is to segregate or partition the software such that the OFP does not rely upon the software to operate time critical functions within the aircraft and the software does not effect the operation of the OFP. In addition, this has the effect of minimizing regression testing of the OFP.

INTEGRATED LVC EXPERIMENT

In 2007, Boeing initiated an Independent Research and Development project to advance the state-of-the-art in Integrated Live / Virtual / Constructive Technologies for Tactical Aircraft Training, entitled Project Alpine. The intent of the project is to build upon the Distributed Mission Operations construct and expand it into the live training domain while focusing on the aforementioned challenges.

The overall objective of the project was to perform risk reduction on the integration of live platforms with virtual and constructive environments for adoption by the DoD and show a dramatic increase in training value. Through the development of network technologies and the integration/maximum reuse of existing assets, the goal was to demonstrate proof-of-concept training capabilities here-to-fore unavailable on platform.

Description/Goal

The demonstration aimed to show the benefits of integrated LVC in a distributed simulation environment. Specifically: 1) Significant cost savings through reduced live aircraft resources 2) The ability to conduct multiple training scenarios in a single live flight without range restrictions on targets or threats 3) The ability to demonstrate operational use of sensors and avionics within a virtual / constructive environment and 4) Reduced mission setup time, allowing missions to be planned relative to a live aircraft and activated in real time. The demonstration involved the following entities:

- One live F-15E aircraft assuming the role of the lead friendly aircraft
- One virtual F-15E manned simulator assuming the role of the friendly wingman aircraft
- Four constructive enemy aircraft generated by the BigTac™ combat environment server
- One weapons server to perform fly-out of missiles launched from the live platform

Figure 4 illustrates a simplified view of the demonstration environment.

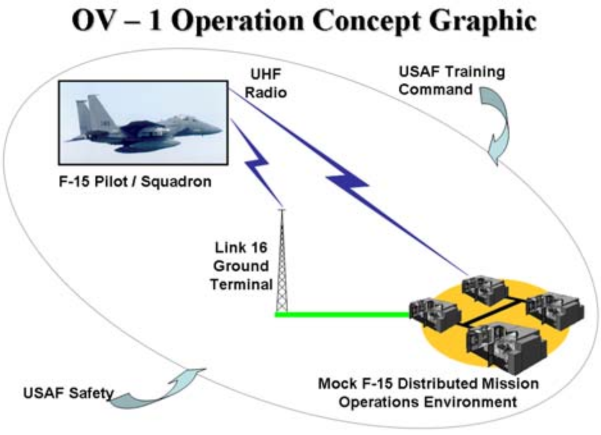

Figure 4 – Operational Concept

Selection of an existing training scenario was deemed important in proving relevancy of LVC technology insertion. The team identified a set of scenarios based on training tasks within the F-15E training syllabus, Air Force Instruction 11-2F-15E, Volume 1. The scenarios were chosen to show tactical 2-ship operations, assuming one live aircraft and one virtual wingman. The demonstration scenarios were beyond visual range (BVR) air-to-air engagements utilizing Radar operation and virtual weapons employment. The experiment was designed to show the ability to inject simulated enemy aircraft into live onboard radar air-to-air displays.

The LVC flight-demonstration consisted of four scenarios. The learning objectives for each of the scenarios are as follows:

1. Target all Factor Bandit groups
2. Sort to appropriate responsibility within Factor Bandit group
3. Make appropriate Offensive/Defensive determination
4. Employ and properly support AIM-120 missile to achieve kill
5. Provide element mutual support

The gaming area used was not a dedicated test range but an area to the north of St. Louis, MO. This area, the Boeing Flight Operations North and South working area is defined by a letter of agreement between Boeing and Kansas City Air Traffic Control. The region included an operations area identified by latitude and longitude restrictions as well as flight elevation constraints.

In order to show training validity, a live-virtual after action review capability was included in the experiment. Data from the live F-15E was synchronized with the virtual/constructive data recorded during the experiment to create a mass debrief capability (ref. Figure 5).

Design Decisions

A conscious decision was made to utilize as much existing software as possible. To that end, the F-15E simulator software is abstracted such that avionics models and network interfaces are segregated from the aircraft Operational Flight Program. Moving this abstraction onto the aircraft, the Radar model from the simulator was ported to the aircraft OFP.

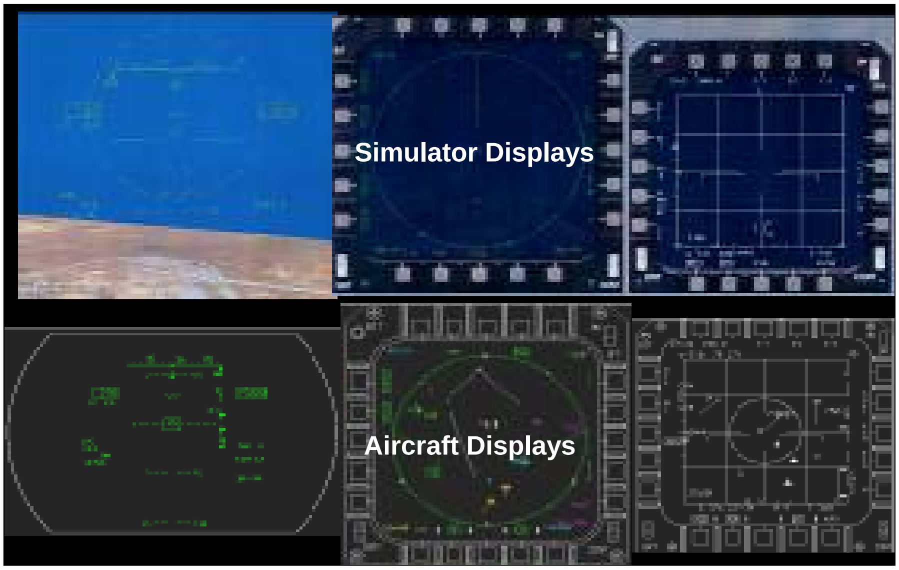

Figure 5 – Synchronized After Action Review

Additionally, the network interface from the simulator was ported to the aircraft OFP, with modifications to support real-time flight operations. A modified DIS interface (airborne DIS Translator and DIS Engine) with a reduced software footprint was implemented to keep impact to the OFP at a minimum.

An iterative approach that repeatedly looked at the trade-offs and benefits of each decision was used to design the experiment. Selection of the datalink for example, involved iterating through a typical scenario and its nominal case as well as the off-nominal, worst case scenario. Multiple variables including available datalinks, number of entities in the scenario, entity behaviors relative to the live aircraft, and nominal versus worst case data rates needed for realism forced multiple iterations of the design. The nominal data rates were based on existing U.S. Air Force Mission Training Center use cases. Several datalinks were evaluated for their bandwidth and availability. Even though other data links may have provided increased bandwidth, Link 16 was selected because it could meet the minimum bandwidth requirements, was approved for secure operations, and is in wide spread use.

To show extension of DMO networks, the DIS protocol was chosen as the network protocol for live to virtual/ and constructive communications. The F-15E simulator and BigTac^{TM} were run on a Distributed Interactive Simulation (DIS) standard (IEEE Std 1271.a-1998) network. Entity updates and weapons firing data were communicated between the live F-15E and the simulation network via the Link 16 datalink. DIS Protocol Data Units (PDU's) were inserted or wrapped into standard Link 16 message packets for transmission to and from the aircraft in order to fit within the prescribe message size on Link 16. The entity updates and weapon firing data were converted from wrapped Link 16 DIS PDU's to DIS PDU's and vice versa by both the aircraft and a ground network gateway (ref Figure 6).

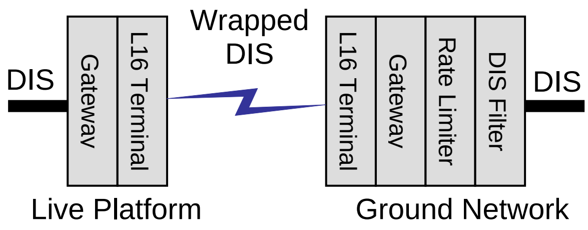

Figure 6 - Ground to Airborne DIS Network

A DIS Filter was used between the ground network and the aircraft to filter unneeded DIS message traffic and protect the flight asset from errant data. A custom message rate limiter was put in place to ensure datalink bandwidth was not exceeded. Voice communications between the pilot on the live F-15E and the virtual F-15E was supported by a UHF radio and conversion to DIS signal PDU's via ASTI hardware.

For the purposes of safety of flight live radar tracks were differentiated from simulated radar tracks via symbology. A unique symbol (horizontal line) was added to virtual tracks reported by the simulated radar. In addition, minor symbology modifications were made to the simulated radar display to differentiate the live aircraft radar from the simulated radar.

Three virtual elements were added to the Operational Flight Program (OFP) of the live aircraft: the F-15E simulator radar model (LVC radar model), airborne DIS Translator, and DIS Interface Engine. An "LVC Process" was created to run all of the logic at one time in an available timing slot in the OFP.

For consistency, the "LVC Process" block was added to a 4ms processing slot. The frame time at initialization of LVC is 61ms, due to non-optimized DIS Engine. This extended process time only occurred for one frame and the overrun was determined to be acceptable. The initialization frame time will be improved in future spirals. The average frame time, while in LVC training mode, was about 40ms of a 20 Hz cycle.

Integration Approach

The demonstration team was fortunate to have a suite of integration assets available that supported progressive integration. The integration of the systems was a three tiered approach moving from the engineering desktop development system to the avionics integration/ simulation lab to the live aircraft. This was crucial for putting together a successful demonstration. The assets included a desktop simulation of the aircraft utilized by the OFP development team. This allowed integration and testing of the LVC specific changes to the OFP without aircraft hardware or a dedicated DIS network. After desktop testing was complete, the OFP moved to the avionics lab where testing was performed with aircraft hardware. The test bench was connected to a Link 16 terminal for further testing. Desktop simulations and existing DIS playback logs also supported development of the DIS gateway, weapons server and simulation components.

The next phase of integration combined the virtual, F-15E manned simulator, and constructive, BigTac^{TM}, elements with the live aircraft hardware test bench. This was the first instantiation of all three LVC components interconnected. In this phase, we were able to validate operation of the LVC network over Link 16, tune rate filters, and priority schemes.

The final phase of integration involved aircraft ground test. The aircraft and avionics integration/simulation lab were separated by approximately one mile. Clear line of sight for the test platform was necessary to establish reliable Link 16 communications. If the system failed a ground test, it was not ground tested again until the problems were worked out on the avionics test bench. The avionics test bench allowed for flexible software debugging (stepping through code, variable watches, etc) not possible in the aircraft.

After successful ground test, the team moved on to flight test. Because of the extensive integration work, only one flight test was needed.

Challenges Encountered & Solutions Chosen

Previous experiments had proven that simulated aircraft could be integrated in live platforms via datalinks in a limited sense. The following section addresses some of the challenges we encountered during this experiment.

Dropouts/Line Of Sight

As with any Link16 datalink, line of sight (LOS) was an immediate concern. Early experimentation has shown the need to handle datalink dropouts of up to two minutes. For the simulation world, packet dropouts have long been a consideration and there are tools to support these issues. DIS dead reckoning technologies used for mission training centers were utilized in the aircraft to account for missed data packets. We implemented a priority scheme for critical data packets.

Safety of Flight

Interviews with test pilots, subject matter experts, instructors and students yielded differing opinions on how to account for safety of flight. Students and instructors were opposed to using unique symbology to distinguish live entities from simulated entities citing negative training. Instructors felt confident that students in live aircraft would behave differently in scenarios knowing that simulated and live entities on their displays were distinguished by using different symbols. The demonstration team chose to implement different symbology for simulated and real entities on our displays. An in depth study considering human factors and training transfer is needed to resolve this issue.

Inputs from pilots and safety specialists suggested that the aircraft radar remain operational during flight. In order to achieve this while the simulated radar was functional we implemented the following capabilities:

- Both the real aircraft radar and the simulation aircraft radar ran simultaneously
- The real aircraft radar was left in the last configuration before selecting LVC mode
- The LVC mode selection was not allowed when the real aircraft radar was tracking a live target for designation
- The LVC mode could be turned off instantly from the aircraft pilot and weapons system officer stations
- The symbology for real aircraft radar tracks and LVC simulated tracks was different.
- Unique radar symbology was implemented for LVC mode

Lessons Learned

A direct quote from the test pilot was "Detections were almost too good.” This is a common complaint among simulation users and quickly moved to LVC. Too often simulated radars are too perfect. Further research should consider how to address the realism of bringing simulated entities into a live environment.

Early involvement of the aircrew was crucial to the success of this research. They were involved in all phases of the effort from scenario selection to final flight.

Comments from demonstration attendees included the need for incorporation of ground threats, use of all aircraft sensors, increased SAM threat density, Integrated Air Defense System nodal degradations, and virtual surveillance and intelligence platforms. Future work will address these requests.

Debrief

Current live asset debrief systems vary greatly as do simulation debrief systems. This demonstration integrated two disparate debriefs systems, the live and simulated. Future demonstrations will need to pull data from multiple platforms for mass debrief. As we move toward integrating disparate systems, standard protocols and interface definitions are needed to bring systems together.

While Project Alpine was a successful demonstration of LVC integrated training, the real benefits are in the lessons learned and the areas identified for standardization and research.

AREAS RECOMMENDED FOR FURTHER RESEARCH

To truly implement an integrated LVC environment for tactical aviation platforms, further development, experimentation, and testing is necessary to provide an understanding of the capabilities, capacity and business model of LVC in an operationally relevant environment on a tactically relevant platform(s). While we were successful in implementing a truly integrated LVC capability for an F-15E aircraft, a detailed test and experimentation plan is needed to address the following areas:

Understand range limitations and how I-LVC can supplement shortfalls

- Cost vs. Payback
- Range implementation challenges – integrating with existing infrastructure

Appropriate use of datalinks and capacities as applied to I-LVC

- Tactical datalink training network and use case
- Range-based training link
- Rangeless operations
- Deployable operations
- Link 16 multi-netting, stacked nets

Training transfer and Safety of Flight

- Symbology modifications, airspace deconfliction, virtual vs. live tracks
- Synchronous debrief of both Live and Virtual entities
- Performance metrics and evaluation
- Training Syllabi enhancement/proficiency

Air to Ground implementation methodology

- Symbology vs. synthetic representation
- Mixed-reality vs. complete synthetic picture

Avionics architectures

- Application to multiple platforms – where is the common dividing line
- Functional allocation / building blocks to implement

Environment correlation

- Ability to tie in multiple platforms from remote locations accounting for both temporal and geopositional shifts

Bounds of using LVC/Use Cases

- Within a range
- Within a Military Operation Area (MOA)
- In uncontrolled airspace
- In theater

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