

## **Advancing the State-of-the-Art in Airborne LVC Training**

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### **ABSTRACT**

There is a significant shortfall in required live aggressor support for 5<sup>th</sup>-generation airborne training. A live Virtual Constructive (LVC) environment could significantly reduce this shortfall by utilizing virtual and constructive forces to supplement live aggressors. However, creating a robust LVC environment capable of supporting advanced airborne tactical training has many challenges including information assurance, platform integration, spectrum availability/compatibility, latency, reliability, and high data throughput requirements. Advanced aircraft sensor simulations require accurate data, driving the need for reliable, low-latency networks. Data exchanged over these networks must be integrated into live avionics systems in real-time to maintain data fusion and prevent negative training while minimizing platform impact and cost. There is significant pressure to sell off the 1780–1850 MHz spectrum that is currently in use by military and training ranges. The DOD is being mandated to either move to other less efficient spectrum bands or cohabit with civilian cell phone systems. To address this mandate and further explore requirements for an on-aircraft LVC instantiation, the US Air Force Research Laboratory is conducting an Advanced Technology Demonstration called Secure LVC Advanced Training Environment (SLATE). SLATE is maturing a spread-spectrum waveform named 5<sup>th</sup>-Generation Advanced Training Waveform (5G-ATW) to test the feasibility of cohabiting with civilian systems that desire to use the 1780–1850 MHz band while providing low latency and high data rates. 5G-ATW will provide the airborne network between live aircraft and ground-based simulation systems to create the LVC environment. 5G-ATW is being integrated into a modified P5 Air Combat Maneuver Instrumentation (ACMI) system and flight tests are to begin in 2018 on an F-15E Strike Eagle modified to support a tactically relevant LVC environment. This paper will discuss technical approaches utilized on SLATE to address design challenges, present findings on the 5G-ATW waveform, and summarize LVC airborne training challenges for advanced platform tactical training.

### **ABOUT THE AUTHORS**

**Lance Call** is a Principal Software Engineer with L3 Technologies at the Air Force Research Laboratory (AFRL). He graduated Magna Cum Laude with a Bachelor of Science degree in Electronics Engineering Technology from Brigham Young University. He has worked on real-time threat systems and integration of live, virtual man-in-the-loop and computer-only simulations. He has been responsible for Cross Domain Security systems and rule set development, improving threat systems, and integrating simulators with live aircraft systems. He is an IEEE member.

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### INTRODUCTION

The ability to support live training with live aggressor aircraft and Surface-to-Air Missile (SAM) systems is expensive and, due to budget limitations, Air Combat Command (ACC) estimates that there will be an increasingly significant flight hour shortfall in the required live Adversary Air (ADAIR) by 2030 (Figure 1). This requires an alternative to

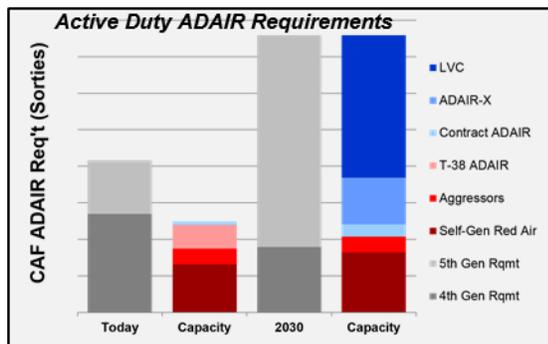


Figure 1. ACC Adversary Air Requirements Summary

live aggressor aircraft and live SAMS be used to augment the live systems to meet the training requirement at a lower cost. We believe that the best way to do this is by integrating the Virtual and Constructive (VC) modeling and simulation technology developed for Combat Air Force Distributed Mission Operations (CAF DMO) into the live aircraft platforms. This would allow VC assets to stimulate live aircraft sensors and supplement/substitute for some of the live aggressor and SAM systems at a fraction of the cost.

To address this need, in 2015 the Air Force Research Laboratory (AFRL) Warfighter Readiness Research Division initiated an Advanced Technology Demonstration program entitled Secure LVC Advanced Training Environment (SLATE). The primary purpose of the program is to develop

exemplars of LVC technology and infrastructure to inform a Program of Record (PoR). The SLATE charter is to:

- Validate LVC infrastructure, interface control, and data standards in a government owned, non-proprietary architecture
- Demonstrate Multiple Independent Levels of Security (MILS) encryption technology and rule sets
- Evaluate alternative large throughput, MILS capable encryptor, radio, data-link, and 5<sup>th</sup>-Generation Advanced Training Waveform (5G-ATW)
- Demonstrate pod form factor
- Develop select weapon system Operational Flight Program (OFP) changes with vendors based upon clear guidelines, resulting in direct risk reduction and leave behind for PoR
- Document training effectiveness benefits and opportunities with integrated LVC capabilities

SLATE uses a modified P5 Air Combat Maneuvering Instrumentation (ACMI) pod. Modifications to the pod consist of a new radio/data link and associated training waveform, pod main processor, embedded LVC processor, trusted guard/cross domain solution (CDS), and a 4-channel encryptor. Additional ground components include a 5G-ATW ground terminal, encryptor, CAF DMO compatible VC devices, and CDS. The host platforms for airborne testing are the F-15E Strike Eagle and F/A-18E Super Hornet, each with a modified OFP to provide a seamless LVC environment on board the aircraft. The SLATE system will be flight tested in the summer of 2018.

Challenges to create an integrated LVC solution include Information Assurance (IA)/Cyber, spectrum availability/compatibility, latency, reliability, bandwidth, accuracy of the data, and platform integration.

## **INFORMATION ASSURANCE (IA)/CYBER**

Transmitting classified data over Radio Frequency (RF) networks entails additional risk for IA and Cyber considerations compared to ground-based fiber or wired links. RF links require additional protection that can be accomplished in two ways. First, the transmission signal can be made difficult to intercept and second, the data being carried by the link can be encrypted to protect the data. The 5G-ATW data link has aspects of both of these techniques. The link randomly hops among frequency channels and also varies its 20 short data pulses in time. Both of these features make the data link more difficult to monitor, intercept, and decode the data.

While encryption is now commonplace, having a high-performance multiple-level encryptor that is small enough and low-power enough to work in a P5 pod is challenging. Under the SLATE ATD, AFRL worked with the National Security Agency (NSA) and Cubic to develop and achieve approval for the new KOV-135 encryptor. The KOV-135 fits into the P5 ACMI pod providing a four-channel MILS encryptor, allowing encryption/decryption of airborne network data. The MILS Encryptor allows up to four different security enclaves to be operational simultaneously. This is necessary to allow 5<sup>th</sup>-generation platforms to simultaneously interact with 4<sup>th</sup>-generation platforms and coalition partners to train the way we fight.

SLATE operates in two different conceptual modes of operation. The first is when the system is communicating with a supporting ground architecture system (we refer to this as tethered); the second is when there are only airborne pods and no supporting ground architecture (we refer to this as untethered).

In order to make use of MILS, there must be a Cross Domain Solution (CDS) device in the pod to exchange data at the appropriate levels. Cubic implemented a rules-based system that is able to implement security rules to show that this is technically feasible. Cubic did not attempt to accredit this device or implement actual CDS rules, but we believe that the approach demonstrated will be able to be accredited in a future PoR and run the required CDS rules.

SLATE demonstrated four notional security enclaves: purple, blue, red, and green/common. The ground system must also have CDS devices. The SLATE architecture will allow reuse and/or adaptation of existing CAF DMO CDS devices and potentially rules, if the desired enclaves are the same as enclaves defined for CAF DMO.

One challenge with connecting live aircraft to the CAF DMO network is that CAF DMO security approvals do not currently include live players or RF transmission networks. These will need to be addressed in the future in order to routinely connect the CAF DMO simulator network with live ranges to implement the long term LVC vision. The long term vision is that CAF DMO simulators and compatible constructive systems will be routinely used to augment and improve live training; and, that LVC training will include full wartime capabilities—including degraded operations environments that are not currently possible in live training for technical or security reasons. It is likely that the majority of operations will be Live/Constructive (LC). However, having the architecture support Virtual allows for not incurring system maintenance costs, flight hours, or TDY costs for Virtual manned red aggressors, as well as JTACS, AWACS, and other C2 and Intel assets that are rarely available for live training. Additionally, LVC is foundational for the ability to access data to objectively measure pilot performance and move from the Ready Aircrew Program (RAP) training approach to performance-based training that could completely transform the way training is accomplished.

Many of the challenges with LVC operations will be related to IA and policies rather than strictly technical. It will be required to address these issues before LVC operations can become commonplace and fulfill their promise.

## **NETWORK**

### **Spectrum Availability/Compatibility**

In 2015, the Advanced Wireless Services (AWS-3) spectrum auctioned off the 1755–1780 MHz spectrum for \$44.9 billion, primarily to cell phone and satellite companies (Cramton and Sujarittanonta, 2015). There has been a significant push to sell off the additional 1780–1850 MHz spectrum to cell phone companies and providers of new wireless technologies. This requires military users currently utilizing this spectrum to either move to other, less effective frequencies or have the ability to operate simultaneously with cell phone systems. The 5G-ATW waveform has been designed with characteristics and capabilities that provide significant flexibility and may allow it to cohabit with cell phone systems. This would allow training systems to use the 5G-ATW in the 1780–1850 MHz band even if those frequencies are sold off.

The 5G-ATW is a 64-frequency, time-hopping waveform spread over up to 100 MHz of spectrum, creating relatively low average power at any given frequency to reduce or eliminate interference with other, non-frequency hopping waveforms. Each message is made up of four sync pulses and sixteen data pulses. These twenty pulses are transmitted on different frequencies. Each transmitter uses a different frequency/time pattern to limit interference. In SLATE, the frequency pattern and time pattern were fixed for each transmitter but, in the future, the patterns could possibly be adjusted on-the-fly to account for other transmitters using the same band. This could be done by changing the hopping pattern to 'skip' over frequencies that are in use by other users to avoid interference.

The Navy is conducting tests in their anechoic chamber at PAX River Maryland with SLATE pods using 5G-ATW, ground stations, and other transmitters including Tactical Target Network Technology (TTNT), cell phones, and P5 ACMI pods to determine the amount of interference experienced by both the 5G-ATW network and the other systems networks. This testing is expected to be completed in August of 2018.

### Maximum Radio Range

For any training waveform, it is desirable to have a very long range capability. In tethered mode, it is possible to create an essentially unlimited range capability by using multiple ground terminals for signal relay. The SLATE pod radio transmits information to the ground terminals. That data is distributed to all ground terminals using a terrestrial network. Then all ground terminals retransmit the data for all airborne radios to receive. This means that the practical transmission range is limited only by the number and location of ground based transmitters. Ground transmitters can also be used to address line-of-site issues.

In untethered mode, there are no ground terminals to assist in relaying network messages. In this case, the system is limited by the maximum range of the air-to-air transmissions and the ability for every radio to relay data if required. For SLATE, the maximum air-to-air range without relay is designed to be 80 nm. It is likely that a PoR would desire a higher maximum air-to-air range without relay. This could be achieved by increasing the radio transmission power and potentially making changes to the antennas used on the pod.

Airborne radios are able to monitor one or more ground terminals using a system of known 5G-ATW preamble symbols that are analogous to multicast groups. This capability allows the airborne receiver to monitor all ground transmitters when the data rates are low and then filter out ground terminals as data rates increase until they are monitoring only a single ground transmitter. This was done manually during the SLATE demonstration by sending a control message from a ground station when high data rates were observed by an operator but could be incorporated into the radio control software to occur dynamically. This approach allows the radio multiple opportunities to receive a message when at low data rates, thus ensuring reliability while preserving the ability to monitor a single station under high data rates.

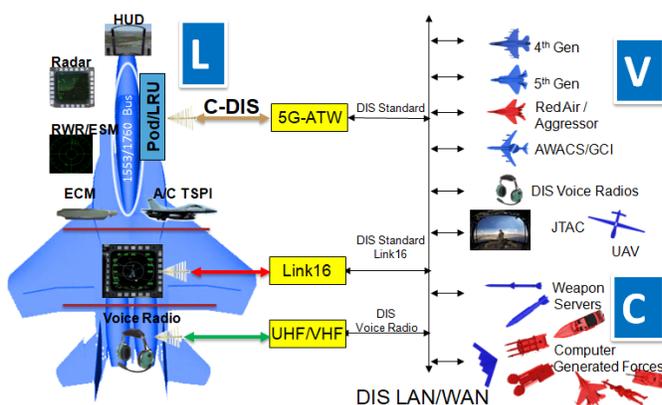


Figure 2. Slate Architecture Diagram

In both tethered and untethered mode, the radio is able to relay data to other radios if necessary. This, however, places additional stress on the network transmission capabilities that is very undesirable.

### Bandwidth

RF bandwidth is extremely limited compared to terrestrial networks. It is therefore extremely important to use that bandwidth very carefully and to take extra measures to ensure its efficient use. SLATE uses the architecture depicted in Figure 2 by using dead reckoning and thresholds to reduce the number of required updates significantly compared to fixed-time update rate systems.

SLATE attempts to re-use existing networks rather than sending all of the data over the new 5G-ATW network. Specifically, SLATE uses gateways to interface VC DIS Link16 and voice radios with existing live Link16 and live voice radios. This means that no voice or Link16 data needs to be sent over the 5G-ATW network. Exact reduction of bandwidth requirements will vary based on the scenario and amount of voice and Link16 traffic. Our IITSEC 2016 demonstration

showed a reduction of 35% while a Close Air Support (CAS) scenario from AFA 2007 that has significant voice traffic was reduced by 60%. We refer to the remaining non-voice and Link16 messages as the ‘LVC’ messages.

SLATE leverages the CAF DMO standard (Northrop Grumman, 2015) that has proven capable of operating over Wide Area Networks (WAN) by using dead reckoning and thresholds to reduce the number of required updates significantly compared to fixed-time update rate systems.

To achieve even further reduction in bandwidth requirements, AFRL developed the Compressed DIS (C-DIS) Standard (Call, 2017) which is able to compress standard DIS LVC message data by 60–70%, depending on the actual contents of the DIS message traffic. Compression is especially important on the 5G-ATW network (which has only 768 bits of user data per message while a standard DIS Entity State message has 1152 bits). This means that the DIS Entity State message must be compressed by 34% or better to map into a single 5G-ATW RF message. If not, then two messages will be required to send each DIS Entity State message, effectively doubling the bandwidth used by the 5G-ATW network for every Entity State message.

Typically, in a multiple level network all data required for a particular enclave is sent over that enclave’s network. In a four-enclave system this would result in many redundant, identical messages in each enclave. If encrypted and then sent over a common RF network, it results in four times the bandwidth for every identical message. Recognizing this, SLATE decided to use a ‘common enclave’ approach shown in Figure 3. Any message that is sent from the Purple, Blue, or Red enclave to Green by the CDS will be blocked from being sent over its own enclave network (Purple, Blue, or Red). The pod will monitor its own enclave plus the Green (common) enclave in order to receive all of the data. This eliminates data redundancies for everything except messages that include guising and therefore must be sent over both Green (common) and the particular enclave color. It was found that, for SLATE, this reduces data requirements by nearly a factor of four because by far most of the data can be sent over the Green (common) enclave. The exact reduction achieved will depend on the enclave contents and CDS rules

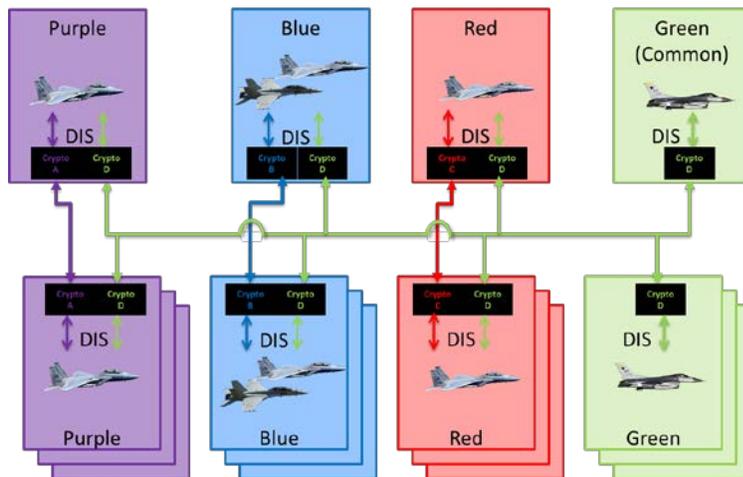


Figure 3. Four Security Enclaves with Common Enclave

amount of interference that would be occurring in data pulses and the large number of receiver resources that would be required.

The 5G-ATW radio implemented for SLATE uses two radios each with eight receiver resources in two 25 MHz-frequency bands in order to avoid transmit-while-receive interference. The receivers are programmed into Field Programmable Gate Arrays (FPGAs). In tethered mode, one radio is focused on air-to-ground transmission and the other is focused on ground-to-air reception. This means that each radio is limited to a maximum receive rate of eight simultaneous messages. This corresponds to 400 messages per second (Mps) x 768 bits per message (user available bandwidth after encryption and all encoding overhead) or 307 Kbits/sec. Larger FPGA's could allow additional receive resources to be implemented that would increase the maximum possible bandwidth due to receive resources.

Even though bandwidth needs can be reduced through data compression and network routing schemes, it is still desirable to have a high bandwidth, low latency network to exchange data. The 5G-ATW network is bandwidth limited by interference and radio receiver resources. The 5G-ATW specification achieves a high bandwidth by allowing multiple transmitters to simultaneously transmit and relies on receivers to have adequate receive resources to simultaneously decode messages. Theoretically, it might be possible for 156 simultaneous transmissions to be occurring based on non-overlapping sync pulse width corresponding to a bandwidth of 4.8Mbits/sec, but this is not likely achievable in practice due to the

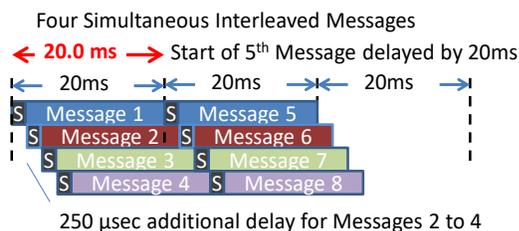
The SLATE ground radios are limited to 200 Mps for simplicity of implementation and potential power amplifier heat concerns, but could be increased relatively easily for a PoR. This means that an airborne receiver should be able to monitor at least two ground terminals, even if the ground terminals are operating at maximum capacity. SLATE will look at sending half of the data from one ground terminal and the other half from a second ground terminal to verify the feasibility of operating at 400 Mps or more in the future.

Another way to improve effective bandwidth is to only listen to data that you need and ignore data that is not applicable. SLATE accomplishes this by implementing multicast groups using known radio symbols in the actual radio transmissions. This allows the receiver to completely ignore multicast groups that are not of interest without even allocating a receive resource chain to process the message. This preserves receive resources. Each ground terminal uses a separate multicast group and can therefore be easily monitored or ignored as desired by the receiver in the pod. Relayed traffic uses specific multicast groups that are only monitored by airborne radios that are experiencing connection issues while other radios can ignore this data without impacting their receive resources.

### Latency

The 5G-ATW network is an ad hoc waveform that allows any node to transmit immediately without any time synchronization required. This means that the radio does not need to constantly stay in sync with other radios and does not require a highly accurate Global Positioning System (GPS) time synchronization. The system does not need to wait for a time slot like Time Division Multiple Access (TDMA) systems, and no allocation of time slots need be assigned or managed as the number of network nodes increases. Adding additional players to the network does not increase the latency.

The 5G-ATW radio implemented by SLATE allows up to four messages to be interleaved and sent simultaneously as illustrated in Figure 4. If four messages need to be sent simultaneously, then the first message would be sent immediately, the second would start 250  $\mu$ s later, the third 500  $\mu$ s later, and the fourth 750  $\mu$ s later. If more than four messages are simultaneously queued, then the fifth message would experience up to a 20 ms delay waiting for the first message to be completed. For live aircraft most messages will not occur simultaneously, resulting in zero wait time before the message is sent and approximately 20 ms for the entire message to be delivered. This operation is consistent with the bursty nature and variable transmission rates of DIS data traffic.



**Figure 4. Simultaneous Message Packing**

When operating in untethered mode, the A/C pod must provide information for constructive entities in addition to its own information. This can lead to additional traffic and potentially increase latency. The radio in the pod is artificially limited (on average) to 50 Mps to ensure that it does not exceed the ability of the radio to dissipate the heat generated by sustained high-rate transmissions but, may burst at rates up to 200 Mps. Additional work on heat dissipation and Power Amplifier (PA) design could allow this rate to be increased in the future.

In tethered mode, the aircraft pod sends data to the ground to be retransmitted. Other aircraft pods can monitor this air-to-ground transmission in addition to the ground-to-air transmissions if they have sufficient receive resources to allow the latency to be minimized for aircraft that are within the maximum air-to-air transmission range.

### Reliability

The 5G-ATW has no explicit reliability mechanism at the physical layer. This was a choice to allow the overhead bits in the protocol be reduced, resulting in efficiencies for the vast majority of data that does not need reliability. The SLATE team developed a network control layer that uses information in the DIS message to implement a send and acknowledge system for PDU's and datums that we felt needed to be sent reliably, such as detonation and remove messages and certain data messages containing specific datums. A table is used to identify the PDU's and specific datums that require reliable communications. The network control layer on the sender side sends reliable messages multiple times according the time delays listed in the configuration file that allow for any desired time delay between additional messages. The network control layer on the receiver side acknowledges receipt of messages on the reliability list. Once the sender receives the acknowledgement or a maximum retry count is reached, the sender stops sending. The Site App Entity (SAE) value in the DIS PDU is used as the sender and receiver ID. Messages that are

broadcast to multiple players, such as a global start PDU, can be configured to be transmitted multiple times without requiring acknowledgement in order to increase reliability without creating a flood of acknowledgment messages.

Being selective in the use of reliability causes the least impact to the required bandwidth. The system can be configured using an editable configuration file allowing for modification as experience is gained with the 5G-ATW waveform performance in real world conditions. The network middle layer filters out multiple messages and deals with acknowledgment and send delays. User applications on the pod are not aware that this is taking place and do not need to send any additional data or handle multiple identical messages.

### Transmit While Receive Interference

The 5G-ATW waveform allows radios to simultaneously transmit and receive data; however, this is equivalent to trying to listen to a whispered conversation while someone is screaming in your ear. The result is that, at relatively low transmissions rates, the receiver begins to miss received incoming data unless special care is taken. MIT Lincoln Labs researched special antenna configurations and systems (referred to as Simultaneous Transmit And Receive (STAR) systems) that may be a technical solution to this problem. Another solution is to provide shielding between two separate antennas. Approximately 70 dB or more separation is desirable. This is effectively done by mounting the antennas far apart which is easy for ground based systems, but difficult for a pod.

For SLATE, we were limited to the changes that could be made to the ACMI pod antenna system. Its antennas are essentially co-located in the front nose of the pod, so we chose to use two radios in separate 25 MHz bands and two antennas, both located on the front of the pod. One radio can transmit to the ground without interfering with the other radio that is listening on the other band for transmissions from the ground. This effectively eliminates transmit-while-receive interference for tethered operations because of the frequency separation of the bands.

In untethered mode, the two radios are used to divide up ownship and constructive data traffic to minimize transmit-while-receive interference to the maximum extent possible. There are several different ways that the data could be divided and SLATE will investigate multiple approaches to research which approach is the best.

### ACCURACY

Accuracy includes aspects of both time and actual value. SLATE uses the CAF DMO DIS standard as an acceptable level of accuracy for training pilots in a robust environment. This level of accuracy may not be sufficient for some engineering development and systems validation and verification activities. Accuracy, in many cases, is a tradeoff between the available bandwidth and the number of entities or sophistication of the systems that are desired to be modeled.

This is a significant challenge. We believe that the CAF DMO approach of providing control data and requiring receivers to regenerate data to the level of fidelity of the platform is a proven and cost-effective way to provide high accuracy and fidelity while minimizing bandwidth requirements.

C-DIS by definition limits the accuracy that data may be represented due to using scaled integer values rather than floating point numbers. AFRL has attempted to use sufficiently accurate values that sensor systems and users will not be affected. A short summary of limitations imposed by C-DIS are listed in Table 1.

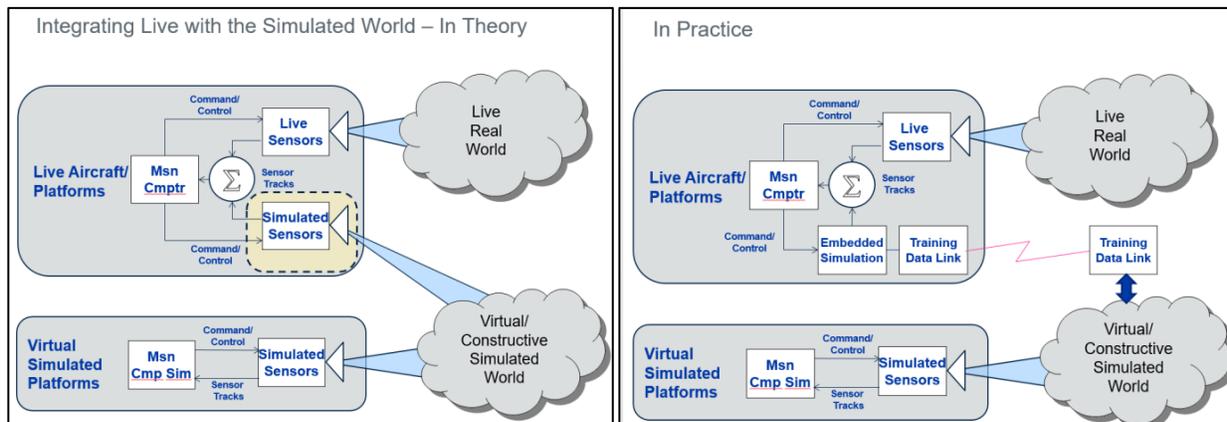
**Table 1. C-DIS Precision Summary**

| Item             | Precision                                   | Maximum Value                                  |
|------------------|---|--|
| Position         | 1 cm or dam                                 | 8388607 cm or dam                              |
| Velocity         | 0.1 m/s (0.194 kn)                          | 3276.5 m/s (6369 kn)                           |
| Acceleration     | 0.1 m/s <sup>2</sup> (0.01 g <sub>n</sub> ) | 818.86 m/s <sup>2</sup> (83.5 g <sub>n</sub> ) |
| Angle            | 0.0439 deg                                  | +/- 180 deg                                    |
| Angular Velocity | 0.35 °/s                                    | 720 °/s  |
| Frequency        | 4 DP (17 bits)                              | 131071 x 10 <sup>15</sup>                      |
| Frequency Range  | 5 DP (24 bits)                              | 16777215 x 10 <sup>15</sup>                    |
| PRF              | 100 Hz                                      | 102.3 kHz                                      |
| Pulse Width      | 0.1 μs                                      | 102.3 μs                                       |
| Power            | 1 dBm                                       | 255 dBm  |

## PLATFORM INTEGRATION

### Operational Flight Program Integration

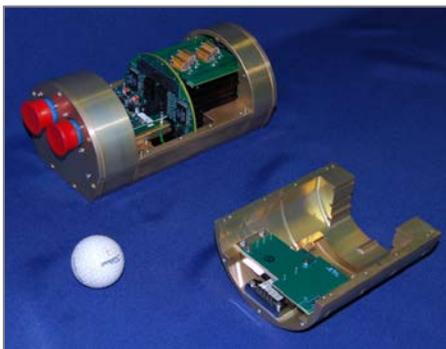
The impact of integrating a networked virtual/constructive environment on a live aircraft can be significant on the OFP. It essentially requires that the live platforms perform many of the same computations that an equivalent CAF DMO virtual simulator performs, then merge the results of these sensor calculations with the actual aircraft systems (Figure 5). Not only must the aircraft computer deal with a second set of sensor inputs, it must manage the data for safety of flight purposes while maintaining a single, coherent, realistic display to the aircrew regardless of where the data came from.



**Figure 5. Integrating Live with the Simulated World in Theory and Practice**

Aircraft are often limited on the amount of computational power available and are, understandably, prioritized for ‘go to war’ tasks rather than training. Adding LVC capability to the Suite 8 F-15 OFP software was pushing the computational limit of the Mission Computer. So, SLATE decided to implement an alternative architecture to address the reliance upon the aircraft Mission Computer and OFP to execute the computationally intensive sensor models.

The SLATE architecture chose to provide computational resources within the externally mounted SLATE pod to support robust, high-fidelity LVC exercises. As shown in Figure 6, Boeing developed a small form factor, multi-CPU module designed as a Line Replaceable Unit for the P5CTS/TCTS Airborne System Advanced Digital Interface Unit, named the LVC Processor Module (LVCPM).



**Figure 6. Live, Virtual, Constructive Processor Module (LVCPM)**

The LVCPM consists of up to six embedded CPU modules, each with 4-core processors (four embedded CPUs were used for the SLATE configuration). The LVCPM also has audio generation capability used to inject sensor and weapons tones into the aircraft crew station.

The LVCPM utilizes ruggedized COTS processors that provide a means to increase the available processing power of the LVCPM as technology increases without effecting the flight certification of the aircraft. The SLATE architecture is not specific to an aircraft type. Software specific to a platform is loaded from external, removable memory at power-on, allowing the SLATE pod to support multiple aircraft platform types.

The LVCPM essentially hosts a DIS-based aircraft simulator less the ownship 6-Degrees of Freedom motion model and engines that are replaced by input from the actual platform. For SLATE, the LVCPM runs a suite of LVC software including the LVC-embedded simulation framework, F-15E 1553 Mux Bus interface module, F-15E sensor model suite, a combat environment server (BigTac™), a weapons server, Real-time Kill Notification, and a Live Gateway. For SLATE, we implemented a full complement of aircraft sensors including the APG-82 AESA RADAR, the ALR-56C RWR, Sniper Pod, air-to-air Interrogator/Identification Friend or Foe (AAI/IFF), and AIM-9 seeker.

LVCPM interfaces to both the aircraft and the airborne DIS network (Figure 7). It sends and receives 1553 operational data to the host aircraft through the Host I/O portion of the SLATE Pod. It sends and receives CAF DMO standard DIS data over Ethernet to the data link portion of the SLATE pod for transmission over the air. This approach allows software reuse of CAF DMO simulator models on the LVCPM. Knowing that each host aircraft type will have unique sensor models and systems, aircraft platforms such as the F-35 may choose to run some sensor models internally and use the LVCPM as more of an interface. This division is a choice made by each aircraft platform.

From the DIS interface, the rest of the pod is common to all platforms. The pod provides a Cross Domain Solution; DIS to C-DIS conversion algorithm; a four-channel encryptor; network management including relay, reliability, and multicast group subscription; and finally, data link RF transmission over the 5G-ATW data link.

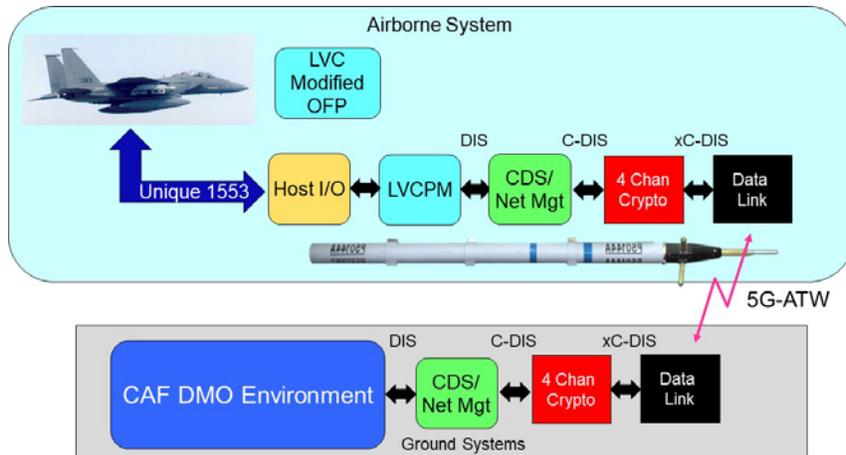


Figure 7. SLATE Airborne Systems Diagram

### Aircraft Bus Bandwidth Limitations

As with most aircraft, the interface to the weapons stations is specified by MIL-STD-1760. The specification includes a MIL-STD-1553 Mux Bus connection to the aircraft. Some aircraft provide higher bandwidth Ethernet to specific weapon stations on the aircraft, but since SLATE is using a modified P5 pod, it is only certified for flight on weapon stations with 1553. Similar to limited RF network

bandwidth, buses on aircraft are also limited in bandwidth and are not designed to pass large amounts

of LVC data. The 1553 has a maximum theoretical limit of 1 Mbit/sec and this may be further limited by the Weapons Station Controller. This is a significant challenge to provide enough throughput to handle injecting a large synthetic force exercise into the aircraft. Additionally, mux bus messages are typically fixed definition messages. For SLATE, we overcame this challenge by creating a variable message interface for the SLATE pod to support a large-scale LVC exercise. The interface is similar to the High Level Architecture (HLA) standard in that a data dictionary is maintained by both the host and receiver and only data that changes is transmitted over the bus, greatly reducing the bus bandwidth required.

### Combining Synthetic Data with Live Data

Referring back to Figure 5, most modern aircraft have some sort of multi-sensor fusion/integration (MSI) capability to correlate multiple sensor tracks for target identification, tracking, and targeting. There are generally two approaches to injecting a synthetic environment into MSI. The first being the injection of the synthetic data in the actual sensors themselves such that the sensors report the track information, typically referred to as stimulation. The second approach involves modifying the MSI algorithms to accept data from additional sensor contributors, i.e., sensor models. The first approach has the benefit of not modifying MSI but has the drawback of modifying the physical sensors to accept the synthetic data (which can be quite invasive to the weapon platform with hardware/software modifications). The second approach has the opposite benefits/drawbacks. For SLATE, the program chose the approach to modify the aircraft mission computer OFP MSI algorithms to accept sensor model input. Both approaches may be viable and are aircraft platform specific, as well as sensor specific.

### Handling Virtual/Constructive Entities on Visual Sensor Displays

Weapons system avionics onboard an aircraft (such as an Infrared Targeting System (Sniper) or the Joint Mounted Helmet Cueing System (JHMCS)) provide targeting cues to aircrew overlaid on visual imagery displays in the cockpit. They rely upon the real world to provide the imagery, including the target of interest (displayed on heads-down displays or via a symbology overlaid on see-through heads-up displays). Whereas in a simulator, an image generator typically renders the scene with the target of interest. In order to combine the synthetic virtual/constructive world with

live visual systems, a method must be designed to either overlay or embed a representation of a target of interest in the real-world imagery.

The sensor models within the LVCPM publish threat track data to the aircraft mission computer just as the live sensors do. Thus, there was no mechanism to send synthetic targets of interest for visual representation to the aircraft. For SLATE, we created the concept of *Network Observations*. Network Observations DIS entities that are observed on the network within the field of regard of the host platform but not targeted by a particular sensor model. *Network Observation* entity type and location are sent to the OFP as additional track information. This is akin to placing a DIS entity within a visual image generator scene on a simulator.

A *Network Observation* track type and position was added to the data sent to the aircraft in the track data. This allows the Mission Computer/OFP to monitor the location and generate symbology that represents the object on visual displays. For the F-15E, on both the Sniper pod and the JHMCS displays, the object is represented by a non-distinct ball meant to represent a 3D object in visual space. The sensors have programmable range bins for proper min/max distance displayed from ownship. This provides for a mechanism to display within-visual-range targets. This approach allows for future upgrades to include 3D model generation onboard the platform for combination with real-world imagery.

In the future, merging 3D synthetic target representations of virtual/constructive entities with the Helmet Mounted Display or Visual Sensors for a more realistic within-visual-range capability may be possible as technology advances. Technical challenges include miniaturizing the processor power required for high-fidelity Image Generation onboard or outboard of the platform; interface to the platform with minimal hardware changes; accuracy in position and terrain modeling/masking; real-world lighting/weather conditions; and, so forth. These challenges were beyond the scope of SLATE.

#### **Adversary Red Air**

LVC must provide a realistic live adversary air picture to the pilots in training. For SLATE, we implemented a guising capability embedded in the LVC modified OFP. Through guising, any live aggressor aircraft carrying a SLATE pod can be identified as an Eastern bloc hostile aircraft by both the live sensors on-board the aircraft and the sensor models in the LVCPM. This is performed through two paths. First, the IFF transponder code sent from the live aggressor aircraft is interpreted as a hostile aircraft; second, the DIS entity enumeration sent from the live aircraft SLATE pod is set to a hostile Eastern Bloc threat. The DIS-based sensor models read the DIS Entity Type enumeration and Force ID and relay it to the OFP as a red threat track information. The aircraft OFP interprets this along with the IFF code and displays it accordingly in the cockpit as a red Eastern Bloc aircraft threat.

#### **SUPPORT FOR TRAINING WITHOUT ANY GROUND SUPPORT EQUIPMENT (UNTETHERED)**

In untethered mode the SLATE airborne system provides a live/constructive (LC) environment. The constructive environment is embedded in the SLATE pod and there are no ground-based VC assets.

While airborne data links typically have a high bandwidth receive capability, transmit capability is limited by size, weight, and power (heat dissipation) of the data link and RF amplifiers. As is the case for SLATE, the P5 airborne environment is a limiting factor. A single SLATE airborne data link is limited to approximately 50 Mps, this is roughly equivalent to the amount of DIS traffic generated by the live aircraft plus four additional constructive aircraft with weapons and sensors. In order to create complex LC scenarios with multiple entities, it is necessary to distribute the constructive force generation across multiple airborne SLATE pods. This distributed approach means that, as additional live aircraft are added to the training event, additional constructive entities may be added in roughly a 4-to-1 ratio.

#### **Simulation Management (SIMAN)**

The SLATE team designed a distributed Computer Generated Force (CGF) capability. This was accomplished by controlling BigTac™ (running in each SLATE pod) remotely from a master airborne simulation manager utilizing the standard DIS SIMAN protocol. A master scenario initialization file is subdivided into subset scenarios and identical copies of the subsets are loaded on all the SLATE pods. Aircrew in any LVC-enabled aircraft can select the master simulation manager from their displays and select a scenario to run. DIS SIMAN commands are sent over the network

from the master to initialize the slave systems and load the selected subset scenarios. A synchronized start allows the scenario to be executed as a whole.

The SIMAN logic is independent of the data link configuration. For SLATE we relied upon the DIS Exercise ID to act as a virtual private network (VPN) among players. As airborne systems join a particular Exercise ID, a SLATE pod registers with each and every other pod on the VPN to transmit status and availability to execute a CGF scenario. Any aircraft may designate themselves as the master controller but, once attained, the design is such that there can be only one master on the VPN at a time (Figure 8). All other SLATE airborne systems on the VPN become slave systems; however, any player within the VPN can issue a TERMEX and end the exercise. If an aircraft must abort a mission, the scenario can carry on without that pod but the system will not have any constructive entities that were being generated by that pod.

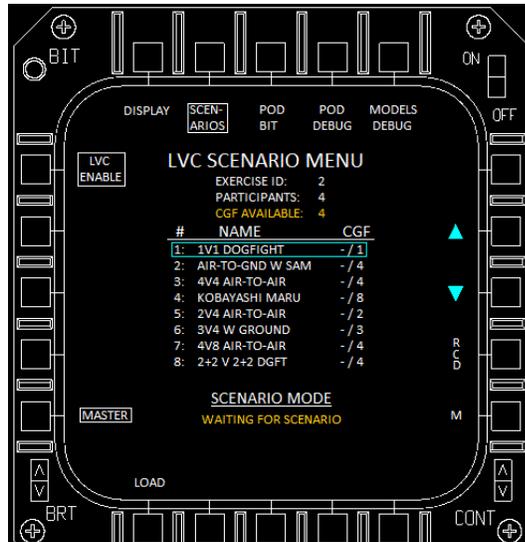


Figure 8. Aircraft Scenario Menu

### Managing Constructive Scenarios

Pilots are task saturated and cannot provide the fulltime attention that a white force operator might during training while flying and training themselves. We limited the pilots' responsibility (Figure 8) to selecting the desired scenario from a short scenario list, verifying that the scenario has been successfully allocated, and then starting the mission. We did implement the ability for the Master Controller to set a push time so that all CGFs will start at a designated time in the future. Once the mission has started, the pilot has no interactions with the CGF until they decide to stop, reset, or freeze the scenario. This limited interaction design is appropriate for untethered training operations.

### RESULTS

SLATE will demonstrate for the first time a purpose-built, dedicated, secure, high-bandwidth, 4-level MILS simulation connection network with sixteen live aircraft that is also, potentially, capable of cohabiting within the same spectrum as cell phones and other users. The system will be capable of operating with range resources in tethered mode or operating

autonomously in untethered mode.

### CONCLUSIONS / FUTURE WORK / RECOMMENDATIONS

Many of the challenges for LVC are policy and IA related rather than technical challenges. It is technically feasible to connect live aircraft in multiple security enclaves with VC entities using CAF DMO standards to create a highly effective and cost-efficient training system that addresses the training gaps predicted in live training. The next step is to incorporate the SLATE system on the Joint Strike Fighter and demonstrate that the system can meet the requirements of 5<sup>th</sup>-generation fighters using advanced sensor fusion, then transition the technology into a PoR for both the Air Force and the Navy. This PoR will cost effectively meet the ADAIR requirements and support a transformation of training for all services from RAP to proficiency based training

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