LVC-Enabled Range Technology: Supporting Training for Next-Gen Weapon Systems

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ABSTRACT

The technology currently available on aviation test and training ranges is insufficient to support current and future operational needs. The capabilities of modern, 5th Generation weapon systems have outstripped the existing range capacities. The result is a gap in the range's ability to support proper employment, realistic operational testing & training, and ever-increasing operations security (OPSEC) requirements. To represent the growing scale and complexity of these threats, protect our employment methods, and adequately train the operational forces, a secure and flexible range construct is needed for highly capable advanced platforms with rapidly evolving tactics. This paper presents the results of recent efforts to understand and accommodate new, blended range training infrastructures that are able to present flexible and consistent Live-Virtual-Constructive (LVC) based environments in a secure fashion. Results from a recent set of experiments and demonstrations show practical implementations of networking, security, platform instrumentation, and simulation infrastructures that incorporate concepts first explored in the Office of Naval Research (ONR) LVC study: Virtual and Constructive Representations on Live Aircraft Displays (VCR-LAD). The live execution and practical implementations of these concepts is presented and explored, including virtual range extension, multi-level secure mission flexibility, and weapons flyout management to maximize the utility of live adversary aircraft. The multilevel security infrastructure detailed supports pre-mission, mission, and post-mission phases of blended LVC operations. We conclude with lessons learned and recommendations for interoperability among advanced range and range-less instances of instrumentation to support both testing and training.

ABOUT THE AUTHORS

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Craig Lewis Smith, Major, USMC (ret.) is a Systems Engineering Manager for Collins Aerospace. Craig retired from the Marines in October of 2017. Over the span of his 20 year career on active duty he served in a multitude of roles including; KC-130 Pilot, Joint Terminal Attack Controller, Operational Test Project Officer, and Modeling and Simulation Officer. His twilight tour was as the Deputy Director of the Simulations and Exercise Support department for the Second Marine Expeditionary Force (II MEF), where he supported II MEF and the USMC efforts to train units using virtual and constructive simulations. Craig is a 2013 Master's Program graduate of the Modeling, Virtual Environment and Simulations (MOVES) curriculum at the Naval Postgraduate School.

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BACKGROUND

Air Combat Training has evolved from the use of purpose built simulators designed to address the training needs of specific mission phases or functions. Purpose built simulators could provide aircrews with flight simulator time practicing night carrier landings or a representative environment for rehearsing flight procedures. Limited integration of procedural and operational simulators followed leading to today's standard for flight simulators. Advances in technology and higher user expectations for realism in modeling complex training environments work together to improve the training solutions being fielded. The concept of blending Live, Virtual, and Constructive elements is an idealized training environment that addresses limitations of range boundaries, practicality of limited resources, and a growing complexity in weapon systems, tactics, and threats.

Today the integration of virtual and constructive elements into live aircraft varies greatly. Most aircraft support the concept of a training mode. This training mode can be specific to an aircraft subsystem such as a flight management system that allows flight planning and dynamic models to "fly the plan" as a training function. More advanced systems enable in-flight training modes, such as Captive Air Training Missiles (CATMs) which facilitate air combat training between live participants on instrumented ranges. However, projection of virtual and constructive elements into live aircraft remains limited. Two earlier examples of this integration were the Air Force Research Lab (AFRL) Project Alpine, and the Office of Naval Research (ONR) Live Virtual Constructive Training Fidelity Program (McLean, 2016), which attempted to improve the flexibility of live training by the addition of virtual and constructive entities. The few existing examples are restricted to experimental range environments with custom integration techniques, well-orchestrated flight conditions and limited test objectives.

The fusion and consistent representation of virtual and constructive data in operational aircraft presents significant technical challenges. Common adoption of emerging LVC technology in the air combat training environment depends on efficient and practical solutions to these problems. The fundamental issue for interoperability is how to represent enough of the simulated world in a live flying aircraft to provide training value without presenting safety issues or negative training through inconsistencies. This paper focuses on certain specific aspects of the aforementioned interoperability challenge. Throughout we will explore optimizing the use of available processing and datalink bandwidth when integrating virtual and constructive elements into the live platform.

New System Requirements For Modern Environments

Modern training range environments are challenged by the need to represent and adapt to the increasing scale and sophistication of emerging threats. This need drives advances in weapon systems and tactics, which places increased demands on the development of and training to new tactics. For live aircraft and the training ranges that support them, the demand for change stresses processing, datalink capacity, and interfaces necessary for LVC interoperability. Training to modern aircraft sensor and weapons capabilities cannot be conducted at the scale and complexity needed within the limited confines of existing dedicated airspace, nor with live participants alone. To address these recognized limitations, new techniques to enhance the training experience are being developed. Our proposed way forward is the incorporation of solid, thoughtful LVC design principles in conjunction with the use of critical enabling technologies required to support the dynamic training environments required by today's Warfighter. The critical enabling technologies include highly accurate Time, Space, Position Information (TSPI), appropriate datalink range, reliability, and capacity, and a multiple independent levels of security architecture that protects data through the use of cryptographic and cross domain solutions. These ideas form the basis of what we describe as Advanced Range Infrastructure and Instrumentation.

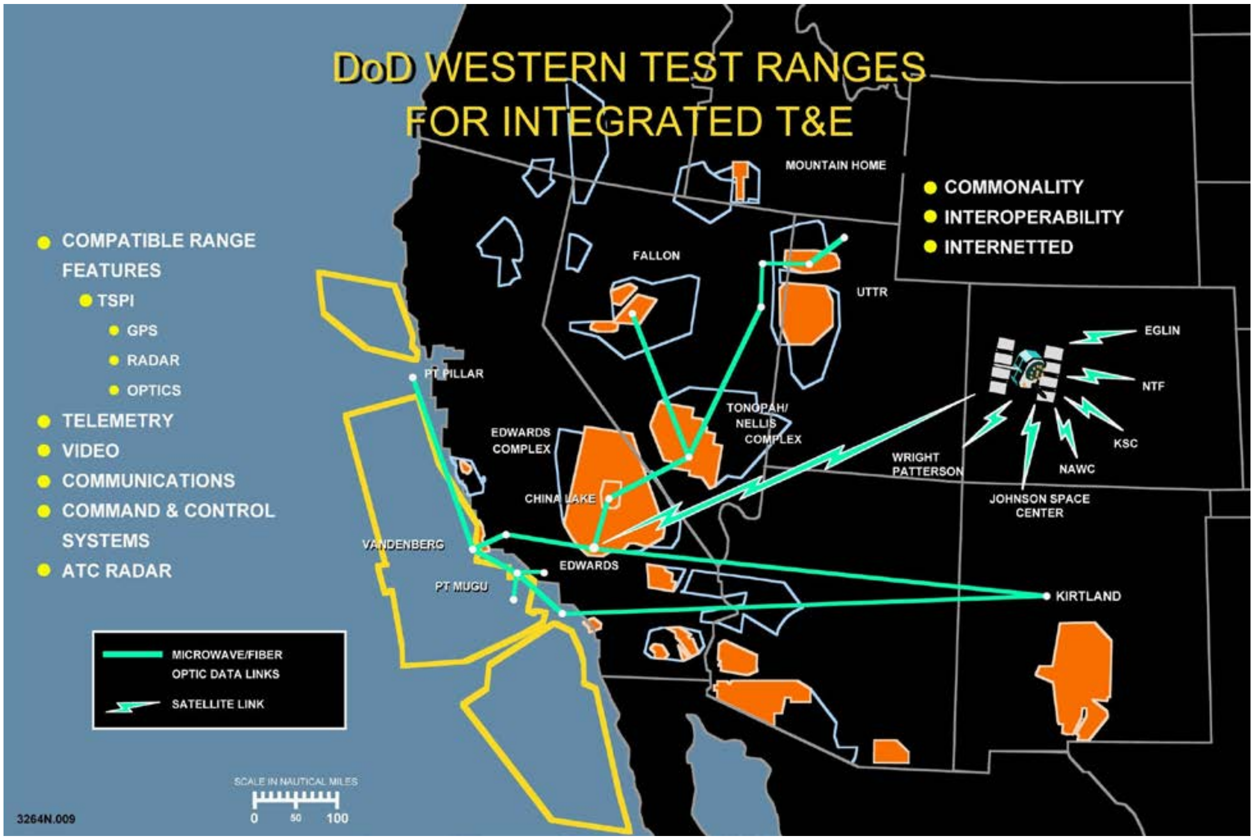

Figure 1. Southwest Range Complex
(Source: https://www.nasa.gov/sites/default/files/images/637646main_SW_Range_complex_slide4.jpg)

Once considered to be a broad expanse of test and training airspace, the Southwest Range Complex (Figure 1) is increasingly insufficient for representing modern air warfare doctrine. In order to cope with contested and denied environments, the maximum effective range of airborne sensors and weapons are dramatically increasing. Practicing extended range tactics is not possible or highly limited within the confines of the existing ranges. To compensate for the relative small size of over land ranges some training is conducted over the ocean, particularly for Naval Aviation, but open-ocean environments lack the range instrumentation that is critical to robust training events.

The need to prevent disclosure of systems capabilities and operational techniques increases the need for and complicates the development of new training instrumentation. To protect knowledge of these capabilities, range training systems must conceal or obfuscate aircraft capabilities and tactics. This includes protecting information transmitted over the air, recorded for later debrief, and the associated weapon and threat simulation data. A lack of multilevel security capabilities prevents live exchange of training information. For this reason, it is common to spend a large amount of post-mission time reviewing range training event recordings to interpret and adjudicate engagement outcomes. A better solution would be to appropriately protect and record adjudicated events in real-time.

RANGE TRAINING INFRASTRUCTURE FOR BLENDED OPERATIONS

Training Range Infrastructure enables live aircraft information collection, recording, and exchange with other aircraft as well as ground based training support activities. Training Range Infrastructure is generally comprised of networks, communications security, aircraft instrumentation, and simulation infrastructure (Figure 2). Typically, on a fixed training range installation, computer-based simulation is used to augment the training environment with constructive entities, and by adding attributes to existing live entities that they may not possess organically. When operating apart from a ground based training range complex, this training network is said to be operating in an “untethered” mode.

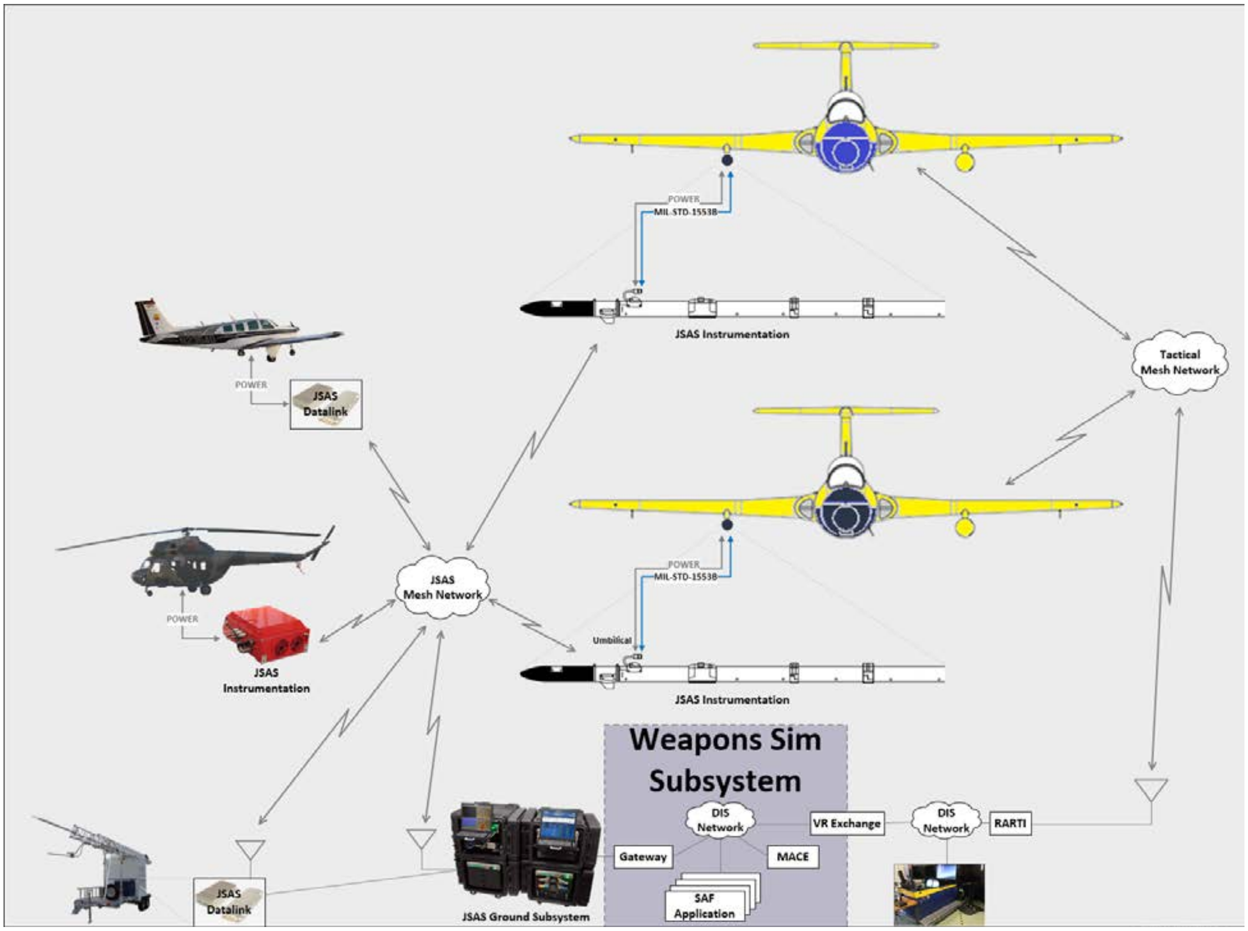

Figure 2. Exercise Architecture

Secure communication includes encryption for protecting data-at-rest and over-the-air transmission of training mission data. Multilevel security support, using encryption and cross-domain message passing, allows secure flows between participant aircraft weapons bus, the training datalink network, and the ground participants. Such security is essential for training to modern tactics, which are informed by advanced sensor capabilities. Since not all exercise participants will need access to platform specific data, segregation and protection of that data is required. Conversely, all participants require some information, such as position and altitude. This suggests the use of multiple, dissimilar security levels which must interoperate in blended training exercises in accordance with data owner rules for sharing. These constraints must be enforced during the pre-mission, mission, and post-mission debrief phases. Since ranges may be used by more than one set of users at the same time, ranges must also support concurrent missions. Live flights during I/ITSEC Operation Blended Warrior demonstrated many of these concepts and served as a basis for follow-on experiments (Gritten et al., 2018).

A blended operations exercise, called Project SLAAM (Secure Live Air-to-Air Mission), demonstrated a training range infrastructure comprised of ground and datalink networks, multilevel security, aircraft instrumentation, and simulation infrastructure. The exercise was the culmination of a series of integration and dry run flights with live, constructive, and virtual participants operating in a variety of modes including live flights, aircraft operating in simulation mode in the hangar, constructive stand-ins, and guising of live aircraft to meet exercise objectives.

SLAAM Flight Tests and Exercise

Project SLAAM demonstrated a Secure Live Air-to-Air Mission (SLAAM) to highlight the joint services developed and fielded Joint Secure Air Combat Training System (JSAS) technology applied to the LVC training domain. The exercise simulated an F-35 engagement of surface-to-air constructive threats, red air live and constructive threats, and protection of an F-15 strike package delivery of bombs on target.

From the University of Iowa Operator Performance Lab (OPL) exercise mission room, the audience was able to see and hear all aspects of the training exercise unfold. From launch, mission execution, and recovery of aircraft, full situational awareness of the event was provided. Digital maps presented a composite real-time picture of red/blue force live, virtual, and constructive participants with real-time tracking information provided by the JSAS pods. Weapon flyouts and kill results were shown for weapon engagements. Tactical datalinks provided visual feeds of the jet aircraft cockpits. Communications included blended aircraft voice communications with digital audio systems from the mission room and virtual simulator.

The exercise successfully demonstrated a live air-to-air engagement of LVC enabled jet aircraft instrumented with JSAS pods. The event included execution of ground based weapon simulations and real-time Range Training Officer (RTO) adjudication of simulated weapon shots from live aircraft. Deployed in an operationally relevant manner, the multilevel security JSAS included multiple remote ground stations and airborne relay nodes. Telemetry data was protected by an NSA certified KOV-74 cryptographic device and message flows between security levels were controlled by the JSAS ground systems cross domain solution. The security infrastructure enabled secure over-the-air communication as well as data-at-rest protection of mission and aircraft bus data.

The exercise scenario (Figure 3) included live aircraft, constructive entities in the form of air and ground elements, and a virtual airborne component. JSAS was operated in the production configuration with the DoD community defined message set for exchanging weapon event and position information between aircraft weapon systems and ground based weapon simulations. The exercise was structured to show how the JSAS operational testing capability could be fielded today to meet urgent air combat training needs.

The exercise scenario included aspects of Offensive Counter-Air (OCA), Suppression of Enemy Air Defense (SEAD), and Intelligence, Surveillance and Reconnaissance (ISR) operations with the intent of demonstrating technology applicability to various training mission sets. Exercise participants included live, virtual, and constructive entities with airspeeds, lethality ranges, and general flow timing adjusted to fit within the civil airspace and dynamic limits of the live participants.

The mission flow included a representative F-35 engagement of surface-to-air threats, red air threats, and protection of the F-15 strike package delivery of bombs on target.

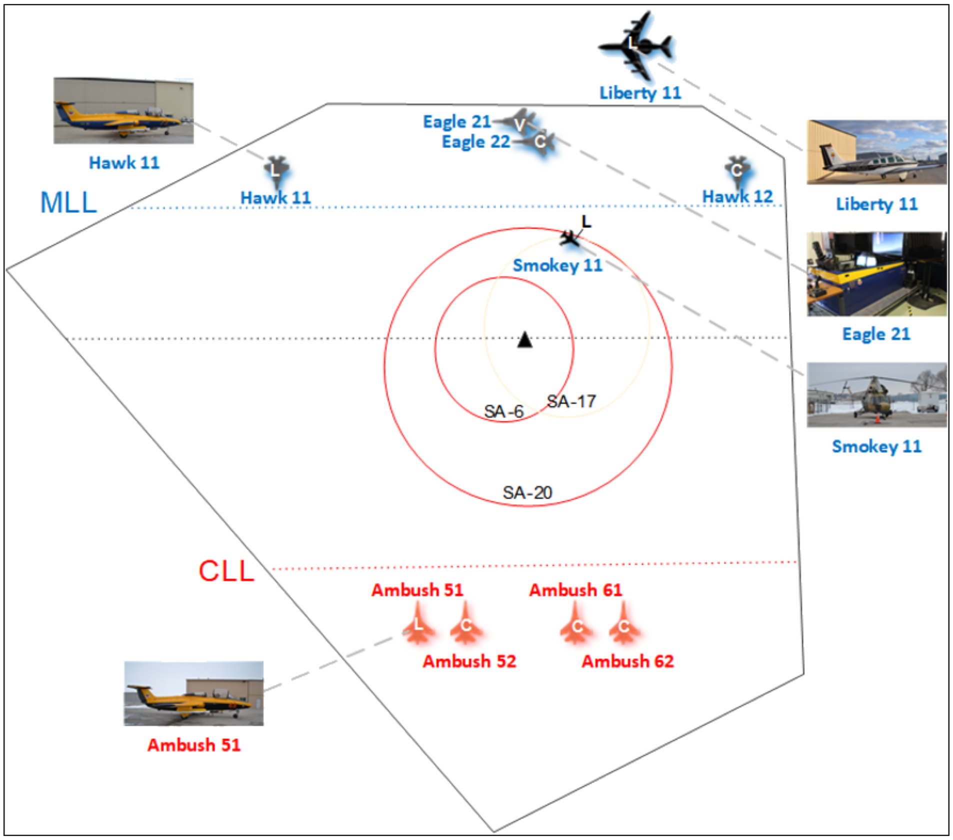

Figure 3. Exercise Scenario

ADVANCED CONCEPTS

LVC Design Precepts for Live Training

Our blended LVC event provided an opportunity to prototype and test several key concepts for integrating LVC into live assets. From the exercise, we've developed the following LVC Design Precepts for Live Aircraft Integration, which include the following:

1. An LVC-enabled aircraft must be able to take LVC input and portray it as if the input data was generated through on board sensors. This most basic requirement defines the intention of LVC integration, but not the mechanism. The implementation could be completely apart from the sensors themselves, completely within the OFP, or an off-board computation that overrides the onboard sensor systems. Note here that we do not distinguish between "flavors" of LVC data. The LVC data injected into a live system may, itself, contain live entity data.

2. An LVC-enabled aircraft must be able to isolate the onboard systems from LVC input. The reciprocal capability, and a logical foundation for safety, is simply the ability to turn the LVC system off, and ensure that the aircraft systems are not injected with LVC data. This obvious requirement is also the basis for other modifications of the fully integrated LVC displays: LVC operating modes where the displays allow the aircrew to understand what is live and what is non-live.

3. An LVC-enabled aircraft should allow the use of onboard equipment in a manner consistent with real-world behavior/operation. This precept reinforces the train-like-you-fight paradigm, and reduces the exposure to negative training, where procedures required for LVC are inconsistent with what would be followed in actual combat.

4. LVC-enabled aircraft must provide a mechanism to gain access to the data representing sensed entities that endures for the lifetime of each entity. The representation of a sensed entity is augmented by modifying the data associated with that entity. When LVC-data is used to do so, the relationship between an LVC entity and a sensed entity must be irrefutable. There are circumstances, such as decorrelation, where a sensed track will become two or more tracks. From an LVC perspective, it becomes ambiguous which of the new tracks was the one being augmented with LVC data. For circumstances such as this, an entity reference mechanism that persists for the lifetime of the sensed entity must be made available to facilitate the association with LVC data.

5. An LVC-enabled aircraft must be able to associate real-world sensor information with an LVC entity, and must be able to correlate LVC data to a real-world entity. This capability asserts the seamlessness of the LVC environment. Computationally, in a purely simulation-based environment, we have the notion of transfer of control of entity attributes. This design precept is the simple application of the concept of transfer of control to an LVC environment. Note that this precept depends on the persistence precept above.

Complex Tracks

The fundamental technical capability explored here goes beyond the ability to insert non-live (virtual and constructive) entities. The design precepts above (number 4 and 5 in particular) propose the association and manipulation of constructive attributes with live assets. For computer generated forces and simulators, these are natural concepts. The use of articulated parts, transfer-of-control and other aspects of interoperability protocols allow for distributed representations of a single system. However, the reality of the actual live platform (aircraft, in this case) precludes treating this as a purely computational construct. We propose an unambiguous label, "Complex Track" or "Complex Entity" to distinguish between purely non-live or unaltered live representations. (Schnell et al., 2015).

Modern military aircraft sensor and weapons systems have the ability to take successive observations, possibly from multiple sensors, to generate a track. The track is the system's identification of an object in its field of regard based upon the apparent correlation of the sensor observations; that is, multiple sensor observations appear to come from the same physical entity. On instrumented live training ranges, such as Air Combat Maneuvering Instrumentation (ACMI) ranges, aircraft provide actual position data to the training monitor equipment. This information can be considered to be more reliable and durable than aircraft sensor data. Similarly, LVC data about non-live entities can be considered "truth" data, and is not an observation, but rather the computed state of the entity. Since we are primarily interested in augmenting the representation of adversary aircraft, we limit our construction of complex tracks to those that can be associated with a training range participant. A complex track, therefore, is the association of aircraft track data (a track file), with LVC entity data by correlation with range data from a live aircraft.

Blended (Live and Non-Live) Training Environments

To provide a richer training environment than can be achieved with available adversary aircraft, the adversarial red force in an LVC training event can be bolstered with virtual and constructive entities as depicted in figure 4 with two blue live training aircraft closing on four adversarial red entities. Of the aggressor force, there are two live adversaries each with a non-live wingman, one virtual (i.e. real pilots participating via a simulator) and one constructive (i.e. semi-autonomous forces driven in simulation). The virtual and constructive additions to the real-world red force could be disguised as and be given the attributes of any aircraft needed to accomplish training objectives (Sherwood et al., 2015).

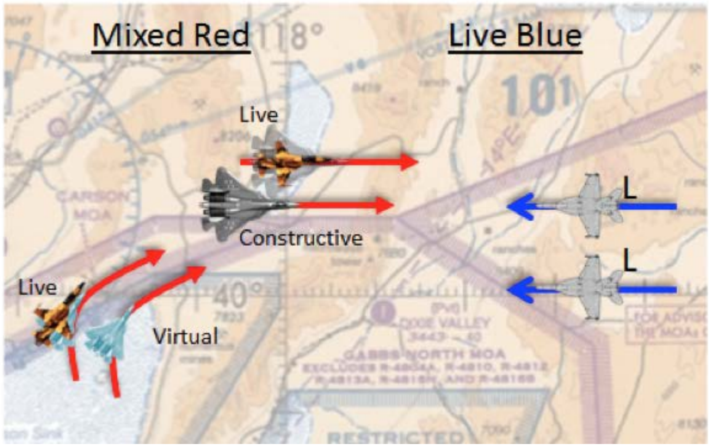

Figure 4. Mixed Flights

Typically, per training rules for dissimilar air combat training (DACT), aircraft are not permitted to leave altitude blocks that segregate opposing forces until they have ALL of their adversary sighted (a so-called tally-ho). This creates a conundrum for the presentation of mixed sections (Figure 4) since it would be impossible for the live fighters to visually acquire the non-live entities. While training rules would ensure the safety of the participants, it also precludes the valuable portions of visual engagements.

We have developed and present a few possible mitigations to this situation as shown in Figure 5. First, it is possible in several cases simply to provide behaviors that preclude the merging of live and non-live entities. For example, it may be acceptable to have the non-live entities exhibit a behavior known as dragging. Behaviorally, this appears to be running away from the engagement. Tactically, this technique can be used to try to create additional separation from an adversary to allow a missile shot or deny an opponent a perceived advantage. It could therefore be completely consistent with the expected behavior of an adversary, and would not necessarily present negative training.

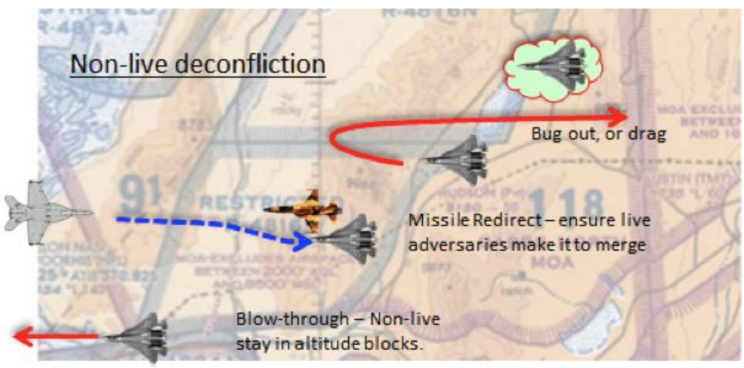

Figure 5. Non-live Deconfliction

Another possibility for precluding non-live merges could be at the other extreme of artificiality. It is possible to simple destroy the incoming adversary beyond visual range, simulating that it had been engaged by some other participant. While this may seem like a logical discontinuity, it can be a perfectly reasonable occurrence in the "fog of war." As long as the LVC-enabled sensors display the phenomena consistently, the disruption and negative training can be minimized. A variant of this behavior can be used in cases where the mixed flight has been engaged by fighters beyond-visual-range. When a missile is launched at a mixed flight, we can inject a preferential behavior whereby it will automatically favor targeting a non-live entity. The non-live entities become "missile sponges," absorbing the attack and allowing the live adversary to continue to within visual range. In several practical tests, we explored the boundary conditions for this novel behavioral construct, identifying situations where it may be perfectly reasonable or appear completely unrealistic.

Finally, a non-live adversary may have a prescribed behavior of simply flying through (blowing through) the merge, quickly exiting the area. Currently, as stated above, training rules would preclude the live aircraft from engaging any live adversaries because of their inability to visually acquire all the aircraft with which they are merging. It may be that in some situations, it is useful for range training supervisors to use this as a mechanism for ensuring the fighters do not engage, forcing a particular tactic or subsequent engagement. Alternatively, it has been suggested that training rules could be modified to allow the delineation of the number of live and non-live entities being approached. A range training officer might announce to the aircrew that they are "merging with 2 live," indicating that visual acquisition of 2 adversaries is sufficient to allow a visual engagement.

CONCLUSIONS

Providing realistic and relevant training for the warfighter is particularly challenging when considering modern weapon systems and their technological sophistication, yet it is critical that these opportunities be provided to adequately prepare our troops who go into harm's way. In this paper we have shown the viability of LVC presentation in live aircraft through advanced range instrumentation. From the experiences gained in practical tests, we assert the value of advanced LVC integration into aircraft presentations. We have built on our prior research to show implementations of advanced LVC concepts, which can extend the training value of simulation enabled training for aircrew and staff from individual TTP through large scale exercise scenarios. In subsequent analysis, we developed some suggestions for ensuring interoperability of live integration strategies which we call LVC design precepts. We have shown the practicality of advanced LVC applications that can extend the utility of precious adversary aircraft assets and improve the training value of live range operations. Finally, during Project SLAAM, we demonstrated complex LVC integration into an exercise which presented the participant with a highly compelling training environment for modern tactical aircraft. Realistic and relevant training can be provided today, the benefits of LVC are gained when incorporating advanced range infrastructure and instrumentation which enable training to be augmented by simulation in the cockpit.

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