3.10 The Human Dimension of Closing the Training Gap for Fifth-Generation Fighters

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Abstract. Based on a review of the recent technical literature there is little question that a serious training gap exists for fifth-generation fighters, primarily arising from the need to provide their own red-air. There are several methods for reducing this gap, including injecting virtual and constructive threats into the live cockpit. This live-virtual-constructive (LVC) training approach provides a cost effective means for addressing training needs but faces several challenges. Technical challenges include data links and information assurance. A more serious challenge may be the human factors dimension of representing virtual and constructive entities in the cockpit while ensuring safety-of-flight. This also needs to happen without increasing pilot workload. This paper discusses the methods Rockwell Collins and the University of Iowa's Operator Performance Lab use to assess pilot workload and training fidelity measures in an LVC training environment and the research we are conducting in safety-of-flight requirements of integrated LVC symbology.

1.0 INTRODUCTION

In early 2011, RAND Corporation published a Project Air Force report titled "Investment Strategies for Improving Fifth Generation Fighter Training" that analyzed the current state of training for fifth generation fighters. Using a variety of data sources the authors concluded that a significant training gap exists. The report also stated that bringing training to acceptable levels would require significant investment by the services.

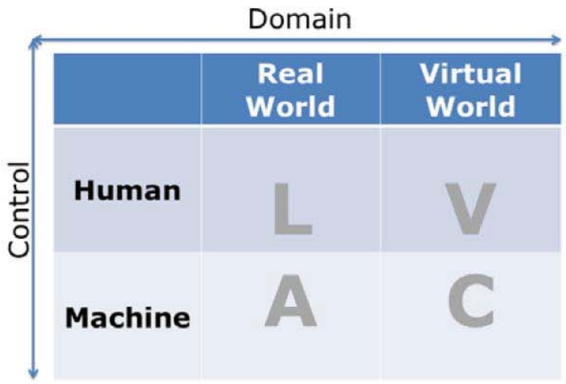
One of the major factors indicating a training gap exists is the so-called "Insatiable Demand for Red Air", or opposing forces. F-22 units are required to provide their own red-air component, meaning the few v. many training exercises utilize almost all available aircraft. To further complicate the matter, using similar aircraft as red air degrades the training received by blue air pilots. Other factors contributing to this conclusion are range and airspace limitations that result from increasing airspace requirements for commercial and general air traffic and the lack of documented training requirements. It is likely that these factors will only increase as the F-35 enters the operational inventory.

These conclusions lead to the obvious question, "How do we close the training gap?" Five options were discussed in the RAND 2011 report, and analysis of the costs associated with each option led the authors to conclude "in the long run, development of the Live-Virtual-Constructive (LVC) ability to inject simulated and constructive threats into live aircraft may be the only fiscally responsible approach to improving training" [1]. Calculating the return on investment for developing this capability is complicated. The technology to accomplish this in not yet fully developed, and as such, the actual costs associated with it are unknown.

Cutting funding for live training to enable significant investments in LVC is not the answer. In fact, this would only widen the training gap. Instead, smaller, strategic investments must be made to address the challenges and mature the technology before any significant investment is made.

2.0 HUMAN FACTORS OF LVC

In order to illustrate our perception of what LVC is, the challenges we associate with it, and our approach when performing research in this domain, we propose the taxonomy shown in Figure 1. We have proposed this taxonomy with the hope that others will add to or challenge its applicability.



	Real World	Virtual World
Human	L	V
Machine	A	C

Figure 1. Live, Virtual, Constructive and Autonomous as related to the worlds and executors of actions in those worlds

The taxonomy illustrates that there are humans and computers executing actions in both the real and virtual worlds. As true LVCA (A represents autonomous systems) environments become a reality, the line between the real and virtual worlds will be blurred, requiring humans and computers to interact in a new, blended environment. Operating in this blended environment gives rise to safety challenges described further in the following sections.

2.1 Challenges

Whereas LVC can provide a cost effective means for addressing training needs, there are several challenges that must be overcome. Researchers active in this domain are quite familiar with two of the key technical challenges, data links and information assurance, but the impact on the operators has yet to be studied in sufficient detail. We will touch briefly on each of these technological challenges, and how they relate to the human dimension, and then discuss the human factors in more depth.

2.1.1 It Is (Almost) All About Connectivity

As the section title states, one of the biggest obstacles is the ability to connect participants. The complete end-to-end connection of participants is at the crux of cracking the LVC challenge. If there are no meaningful ways to enable information exchange between the players, then discussion of the LVC topic is moot. The virtual and constructive threat information cannot be injected into the live platform if it cannot reach it.

Unlike virtual platforms on the ground that can be easily connected via optical fiber, the live platform data links must go over the radio. The real world presents challenges for maintaining connectivity at long distances when the live participants move at various speeds, with different orientations with respect to receiving antennas, etc. The sheer volume of data required for real-world scenarios also presents a significant obstacle and drives the requirements for data link robustness, as well as traffic shaping and scheduling algorithms. It may not be appropriate or practical to burden tactical networks with training data, as is done in the approach discussed by Lechner and Wokurka [2]. Appended LVC systems may require a separate data link, allowing preservation of tactical network bandwidth for operational communications rather than for training data.

Incomplete or inconsistent representation of virtual/constructive training data may be the result of data link latency, loss of data link, or data routing issues. Large entity counts that may be generated by LVC federations can quickly exceed the physical limits of the data link, giving rise to the potential for lost or non-transmitted tracks. Entities that are conveyed through a data link may generate tracks that can become stale or desynchronized when the data link breaks during aircraft maneuvering or due to flight outside the data link operational envelope. Tracks that become stale or disappear due to data link outages will cause confusion in LVC participants, especially in exercises with very large entity counts. The confusion of tracks among LVC exercise participants may result in degraded training and may also cause unsafe merges between live aircraft and non-participating traffic or interlopers.

2.1.2 If Data *Can* Reach the Destination, *Should* It?

Assuming the data link challenge was solved and traffic could flow from one participant to another, it does not mean it is *allowed* to flow, according to classification rules. This cross-domain challenge is related to the fact that the virtual world must address security concerns often present in the real world scenarios. For example, an LVC system connecting a U.S. Marine Joint Terminal Attack Controller (JTAC) at the unclassified Camp Pendleton simulation facility to the Nevada Test and Training Range, which operates a number of Secret and Top Secret aircraft platforms, would be completely useless without a process for handling the hierarchies of data distribution and crossing classification domains.

Figure 2. Cross domain solutions are a necessary component of network-centric environments, such as LVC systems, that require information sharing across all security enclaves

Because High Level Architecture (HLA), the protocol used for many distributed simulations, is based on a publish-subscribe mechanism, any participant can subscribe to information from other participants. From a security perspective, this reduces the amount of control over the data flowing between the participants and presents the risk that sensitive information about planned missions, performance capabilities (platform, sensors, weapons, etc.), locations of facilities, task force composition, tactics, doctrines, etc. may be disclosed. Möller *et al.* [3] explore several different techniques for handling the cross domain challenge, most of which involve limiting and/or obfuscating the data being passed between the participants.

What impact does this limited, degraded, or complete lack of information have on the trainees? Is the information good enough to still provide effective transfer of knowledge? Or, perhaps more concerning, does it result in *negative* training? We pose these questions knowing that there currently are no definitive answers.

2.1.3 The Human Dimension

Whereas the integration of virtual and constructive elements into live training opens up new avenues for training, it also raises concerns about safety of flight. When needed, aircrew integrated into this blended environment must be able to differentiate between actual and artificial entities or threats. Additionally, aircrew manning live aircraft will be expected to continue to execute their original duties while coping with with the changes introduced by these modifications.

The first, and probably most obvious, concern is an increase in cognitive workload - the complexity and confusion that could occur when additional information is introduced into an already complex systems management problem. Minor increases in pilot workload can have an impact on safety critical tasks, such as visual search strategy and threat deconfliction methodology. The training benefits of LVC could be easily offset if this flight safety hazard is not mitigated appropriately.

A second area of concern lies in the misinterpretation of virtual and/or constructive symbology or annunciations. Lacking appropriate safeguards, a pilot could misinterpret a live entity as a virtual input and, considering it to be a training target, perform inappropriately threatening maneuvers or obtain radar lock against a live aircraft not participating in the training exercise. These types of actions could result in a real-world rules-of-engagement violation. Conversely, misinterpreting a virtual entity could lead to risks such as fuel emergencies as a result of flying to a simulated tanker, performing high risk maneuvers to engage or evade a virtual entity perceived to be a genuine threat, or disrupting the exercise due to a traffic conflict that does not exist in the real world.

Until quite recently, these concerns caused decision makers to be reluctant to add LVC capabilities to operational and readiness training. In certain training environments, instructors can provide a margin of safety for an overloaded student, but when an LVC environment is applied to operational training and readiness there is no dedicated instructor. Mitigating the safety of flight concerns can possibly be achieved through the use of distinct symbology and/or annunciations that allow the pilot to quickly distinguish between information based on real-world data and that generated by virtual and constructive participants. However, any additional cognitive workload induced by blended symbologies, annunciations, and training scenarios must be handled in a manner that does not further compromise pilot safety.

2.2 Quantifying the Human Dimension

Until quite recently, the human dimension has been largely overlooked. Interest in quantifying the impacts on operators has increased, as evidenced by the Office of Naval Research (ONR) Broad Agency Announcement (BAA) 11-005 [4], initially posted on December 3rd, 2010. The BAA contains three technical areas that focus on the training fidelity concerns in the live, virtual, and constructive domains respectively.

Our research team has a four year history of conducting LVC exercises integrated in the U.S. airspace, and has developed a real-time workload measurement system for use in both aircraft and flight simulators. Although this neuroergonomic operator monitoring and evaluation system [5] [6] was developed independent from the LVC research conducted by the team, it is well suited for pilot performance assessment in integrated LVC environments. Our research team has a number of experimentation systems already in place, including two L-29 jet aircraft and several reconfigurable simulators, which are equipped with these tools to evaluate pilot workload and training effectiveness. Successful tests have already been conducted in flight simulators, research vehicles, and flight test aircraft [7].

The Cognitive Avionics Tool Set (CATS), shown in Figure 3, uses neurocognitive and physiological signals to generate a real-time measure of cognitive workload. CATS uses data from respiration, electroencephalogram (EEG), electrocardiogram (ECG), eye tracking, and galvanic skin response (GSR) sensors to measure a wide range of human neural and physiological characteristics. State-of-the art active shielding electrodes, combined with filtering and processing techniques, are used to reduce the effects of adverse noise and signal acquisition. The CATS framework was designed to easily accommodate new sensors and analysis techniques.

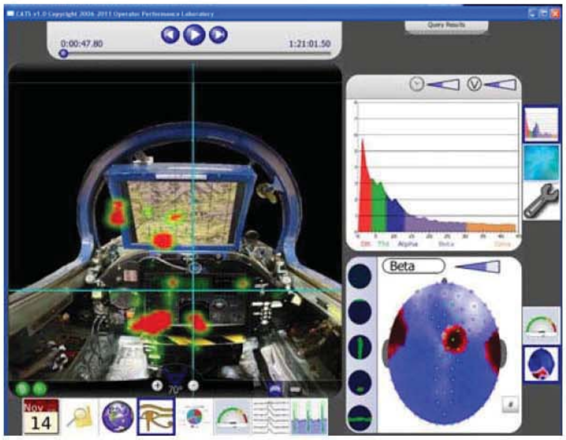


Figure 3. CATS workload monitoring system

A highly integrated and ruggedized instrumentation package, with a single point umbilical connection to the aircraft or flight simulator, simplifies the deployment of neurocognitive and physiological sensors. EEG electrodes have been integrated into the liner of a flight helmet and the respiration belt and ECG electrodes are worn under the flight suit. All peripheral electronics have been integrated into a pilot survival vest.

The Quality of Training Effectiveness Assessment (QTEA) tool [6] uses data from CATS and quantifies pilot performance against set performance requirements. Both systems record a rich dataset, containing hundreds of variables that constitute some form of measurement of effectiveness, for further offline analysis. CATS and QTEA provide powerful, state of the art analysis capabilities, and our current research plan involves applying these tools in an LVC environment to assess symbologies for injecting virtual and constructive entities into live platforms.

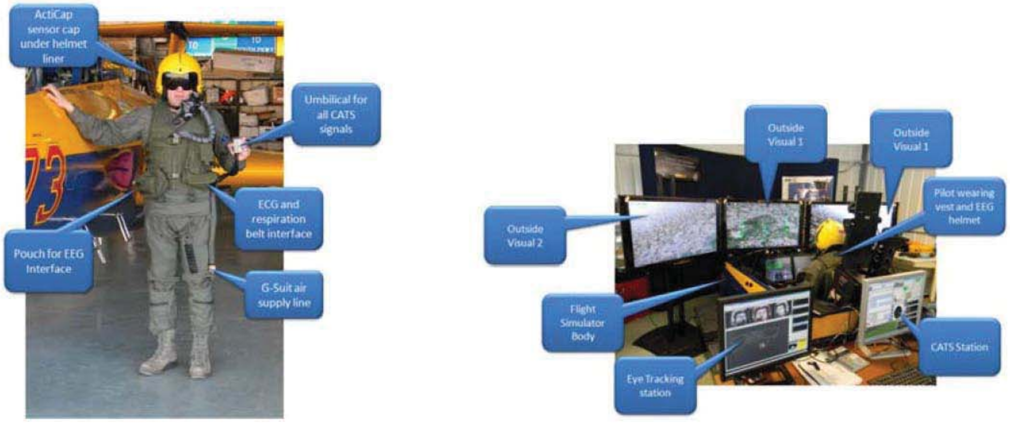
3.0 DISCUSSION

Workload and performance are fundamental considerations when designing new aircraft or weapons systems. To successfully augment real world inputs with training inputs coming from simulation systems the original design factors must be modified, and the viability of these modifications must be tested in the cockpit. Using both in-flight and ground-based evaluation systems, our team is conducting research into LVC-aware avionics symbology and annunciation sets and guidelines for LVC-aware avionics.

Candidate symbology design and development of simulation based prototype displays is being driven by requirements definition and stakeholder needs. Human-in-the-loop testing will gather data on the impact to safety of flight and training effectiveness of the symbologies. Tests will be conducted in an environment drawn from an application of mission tasks to a notional LVC training scenario, and performance data will be gather by CATS and QTEA. The tools will be deployed within our existing LVC framework to obtain real-time measures of workload, situation awareness, and pilot performance on the basis of neurocognitive and physiological measures as well as mission and flight technical performance measures. The combined system of human performance assessment tools and LVC capabilities available to our team provides a unique evaluation platform for collecting quantitative data on the suitability, workload, and cognitive demands of the proposed symbologies and annunciations.

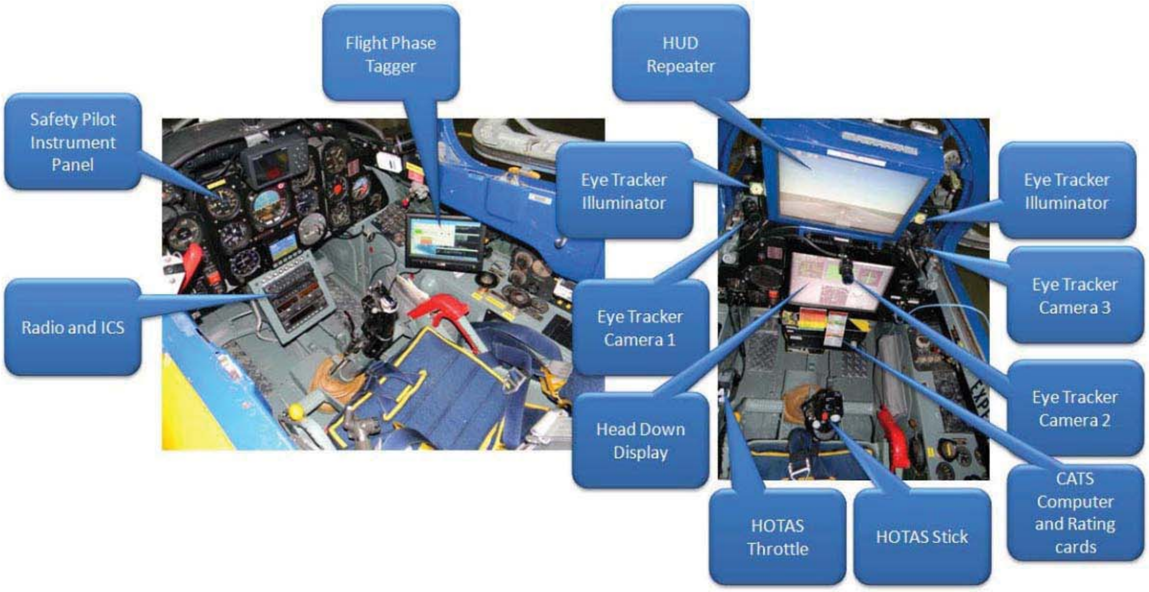
Our experimentation system, shown in Figure 4, includes two L-29 jet aircraft with modified evaluation cockpits in the rear seat, integrated instrumentation pods, a ground support infrastructure, a reconfigurable single-seat simulator and an operator monitoring and evaluation system. This constellation of assets will allow our team to test the performance of multiple crews in an LVC exercise and conduct human-in-the-loop testing in both the reconfigurable flight simulators and LVC-enabled live aircraft. The system will also allow evaluation of the display prototypes to make strong claims about the validity and effectiveness of various virtual and constructive symbology insertion methods in a much more effective manner than traditional human factors data collection techniques, such as pilot surveys.

At this stage in our research, we foresee symbology variations using multiple stimulus dimensions for differentiating between live, virtual, and constructive entities. Variations include, but may not be limited to, symbol color, size, fill, shape, text legend, style (dashed, dotted, solid), blinking (speed, duty cycle), fading, and contrast polarity. Variations in auditory annunciations to distinguish between entity types will also be investigated, including dimensions such as voice (male vs. female), amplitude, frequency, waveform, envelope (attack, sustain, release, decay), and stereo vs. mono. Additional variables that will be considered are type of display (visual, auditory), display location (head-up, head-down, helmet), and scenario related settings. We are also considering the potential negative impacts of allowing trainees to distinguish between live, virtual, and constructive entities, and the possibility that the highest quality of training may occur when they cannot.



a. Pilot with Sensor Vest

b. Flight Simulator



c. L-29 Front Cockpit

d. L-29 Rear Cockpit

Figure 4. Instrumented Flight Simulator and Matching L-29 Flight Test Aircraft

As a byproduct of the design and testing efforts we plan to deliver LVC training safety and training effectiveness assessment methods and preliminary design guidelines for LVC datalink technology. Where practical we will develop detectable criteria to indicate a potential loss of real-world situation awareness or other safety of flight concerns, and propose display modes and/or annunciation to prevent the development of flight risks that may arise when virtual and constructive entities are injected into live systems. Our goal is to provide traceability from measured pilot performance, through analysis and design, back to the mission tasks and requirements definition. We will show how specific symbologies and avionics configurations map to the ability to safely conduct LVC training to meet training and readiness requirements. Upon completion of this research we will demonstrate that the final design meets the requirements for mission training, and has a known, negligible impact on safety of flight.

4.0 CONCLUSION

A significant training gap exists for fifth-generation fighters, and a recent study identified the LVC ability to inject virtual and constructive entities into the live aircraft as the most cost effective solution. Although the technical challenges associated with integrating live equipment into LVC environments has received significant attention, the effect on the operators has not been studied in detail. This human dimension can have a significant impact on the training benefit and acceptance of LVC for operational and readiness training.

Our research team is conducting design and experimentation work to determine LVC-specific guidelines and symbologies that enable safe and effective insertion of virtual and constructive entities into live systems. An iterative research cycle that draws upon the team's extensive human factors experience will continue to evaluate and improve symbology and update guidelines throughout the research period. Because of the comprehensive instrumentation we have available, and our successful testing track record, we will be able to identify design considerations and present strong quantitative and qualitative evidence to support our final conclusions. At the time this paper was written, preliminary results were not yet available.

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