Nationaal Lucht- en Ruimtevaartlaboratorium

National Aerospace Laboratory NLR

Executive summary

Embedded Training and LVC

Problem area
Embedded Training (ET) provides many benefits for education and training on individual, team, and inter-team level. Furthermore, ET enables the integration of platforms equipped with ET into a Live-Virtual-Constructive (LVC) environment, as ET already integrates a constructive simulated environment into a live environment. Blending LVC and ET presents opportunities to flexibly scale training application from individual training to large scale air operation and joint training exercises.

Description of work
This paper elaborates the position about blending ET and LVC, the benefits that can be gained from ET enabled platforms in LVC environments and how both technologies - together with pure live, virtual or constructive training - co-exist well to provide optimal flexibility to tailor operational training. Some technological challenges are still to be addressed; not so much specific to ET/LVC integration, but for LVC at large.

Example: the usage of wider area lower bandwidth data-links to communicate virtual and constructive simulation data with live platforms; here ET technology offers opportunities to distribute constructive simulations based on the level of interaction in the scenario.

Results and conclusions
There are several reasons why LVC without an advanced ET capability cannot reach the full training potential of having both in synergy.

ECATS (Embedded Combat Aircraft Training System) is an extensive ET application for fighter aircraft that has been developed by Dutch Space and NLR in The Netherlands. It is a prime example of high-fidelity constructive simulation embedded in fighter aircraft and is used as the baseline for the argumentation in this paper.

An ET application like ECATS has the distinct advantage of requiring almost no specific organised infrastructure to use it. When using it, it merely requires the selection/creation of training scenarios which would of course also be required for an LVC training. ET training can be performed easily anytime anywhere and with a library of training scenarios available the setup of such

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ET exercise can be fully and smoothly integrated into the regular mission planning, briefing, execution, and debriefing cycles. There is no limitation to certain training areas; there is even the possibility to use ET while stationed in an operational area to limit the loss of full mission readiness of pilots that are active in an operation.

On the other hand an ET capability is generally more limiting in scope, in the sense that an LVC solution with ground/air data links is better suited to training exercises with a scale beyond inter-team training. As is shown in this paper, ET technology and LVC technology are a natural fit and ET technology enhances LVC integration on ET enabled platforms. The availability of an advanced ET live constructive capability means that there is an opportunity to alleviate some of the challenges encountered by e.g. bandwidth limitations of ground/air data links.

As a conclusion it is stated that advanced ET applications like ECATS are enablers for successful LVC applications. Blending LVC and ET presents opportunities to flexibly scale training application from individual training to large scale (air) operation and joint training exercises with the most effective use of scarce resources.

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Contents

Abstract

Development of an integrated Embedded Training (ET) capability for the Joint Strike Fighter (JSF or F-35 Lightning II) is in progress. The core of this advanced ET implementation has been researched, matured, validated and is now being developed for the F-35 by the Dutch consortium formed by Dutch Space and the National Aerospace Laboratory NLR. This advanced ET technology is integrating constructive simulation into the heart of live training, on the live platform itself.

Embedded Training provides many benefits for education and training on individual, team, and inter-team level. Furthermore, ET enables the integration of platforms equipped with ET into a Live-Virtual-Constructive (LVC) environment, as ET already integrates a constructive simulated environment into a live environment. Blending LVC and ET presents opportunities to flexibly scale training application from individual training to large scale air operation and joint training exercises.

This paper elaborates the position about blending ET and LVC, the benefits that can be gained from ET enabled platforms in LVC environments and how both technologies - together with pure live, virtual or constructive training - co-exist well to provide optimal flexibility to tailor operational training. Some technological challenges are still to be addressed; not so much specific to ET/LVC integration, but for LVC at large. Example: the usage of wider area lower bandwidth data-links to communicate virtual and constructive simulation data with live platforms; here ET technology offers opportunities to distribute constructive simulations based on the level of interaction in the scenario.

The position presented in the paper is based on more than a decade of research, maturation, validation, and the current development for the F-35 of advanced ET. This paper describes how ET enabled platforms provide the technological basis for integration into LVC environments. ET and LVC together provide flexible operational training capabilities.

1 Introduction

Both virtual man-in-the-loop simulation and constructive simulation have existed alongside each other and interconnected for quite some time now. Constructive simulation has, for example, been used for scenario generation to train operators in connected virtual simulators and strategic war-gaming to train commanding officers. Virtual simulation has been mainly focussed on single operator/single crew training until the 1990´s, with developments to gain the benefits of interoperating virtual simulation starting as early as the 1980's. With the advances in computing and networking technology of the 1990´s and in the 21st century, large scale distributed mission simulation (DMS) has become feasible. As a result the use of has spread at a fast pace.

Simulation on live platforms is often constrained by limited available computing resources, especially on flying platforms. Only in the last decade computing technology has evolved such that application of advanced Embedded Training (ET) simulation has become feasible for high-performance fighter aircraft. ECATS (Embedded Combat Aircraft Training System), the advanced ET application that has been developed by Dutch Space and NLR in The Netherlands (Ref. [1], [4], [5], and [11]) is a prime example of high-fidelity constructive simulation embedded in fighter aircraft.

Major improvements in technology over the past decades strongly progressed means of training by simulation; taking live simulation to a new level and providing grounds for the realisation of Live-Virtual-Constructive (LVC) training. In LVC terminology ECATS is a Live-Constructive (LC) training application, whereby the simulation is embedded in the live platform. The necessary hardware systems to operate ECATS can either be fully integrated into the platform or attached to the platform on a suitable hard-point. The scope of definition for ET and LVC as is assumed in this paper is defined in section 2.1.

Next to the development of advanced ET technology, the Netherlands have also been performing extensive research on distributed mission simulations, not only focussing on the networking aspects but also on integration at the semantic levels of interoperability (Ref. [7] and [10]).

This paper presents a position on blending ET and LVC which is founded in the research and development of the past decades. First a background will be provided that sets the scope of definition and explains the Dutch R&D efforts in more detail. The heart of the paper will present the position on ET and LVC integration from both a training as well as a technology point of view. Some concluding remarks will summarize the position that is taken in this paper.

2 Background

There are various definitions of what ET is and to a lesser extend what LVC is. These definitions of ET have large differences in scope. Adding further to the definition problem is that in most cases Embedded Training should have better been called Embedded Simulation as there are no integrated training aids. So first this paper will set the scope of definitions as are assumed in this paper.

2.1 Setting the Scope

The term Embedded Training is in general used in a wide scope to describe any training capabilities built into or added onto operational systems, sub-systems or equipment. ET enables operators to use their operational systems and equipment in a mode where some of the real equipment is simulated/stimulated in a training mode. Often these ET applications do not offer a virtual tutor per se and are thus really more Embedded Simulations.

The ET application that is covered in this paper is an advanced ET application for fighter aircraft called ECATS (Embedded Combat Aircraft Training System). ECATS has been researched and developed in The Netherlands by Dutch Space and NLR. It provides the war-fighter the capability to train against virtual threats that are generated by a constructive scenario simulation capability embedded on-board the aircraft. ECATS provides both virtual air and surface threats, is not dependent on range equipment, and can be implemented as a pod or completely integrated into the aircraft mission system.

This paper assumes the following definitions for LVC:

- Live: a platform or system as it is in actual use by military operators; this includes special training equipment like trainer aircraft.
- Virtual: an operator-in-the-loop simulation of a live platform or system.
- Constructive: a simulation of a live platform or system whereby also the operator is virtualised.

2.2 Research and Development on ET and LVC

2.2.1 R&D history of ECATS

Late 1990's Dutch Space and NLR started to elaborate a practical ET system for fighter aircraft that would become ECATS. First demonstration of its potential was realised in 2000 by embedding in the research fighter aircraft simulator GFORCE at NLR. This was followed by an integration of ECATS in the an F-16 MLU of the Royal Netherlands Air Force (RNLAF) in 2004; this demonstration was realised in only 8 months and was received very well by all participating fighter pilots (Ref. [1]). The successful demonstration of single ship ECATS led to the conclusion that enhanced ET in fighter aircraft is feasible and has huge potential for cost savings and more effective training.

A follow-on study for the RNLAF researched multi-ship feasibility for F-16 aircraft; it included research on solutions for synchronisation and also provided a cost-benefit overview to demonstrate that this capability is economically worthwhile. This study showed that multi-ship ECATS integration in the F-16 aircraft is not only technically feasible but also economically attractive for the operating services, in this case the RNLAF (Ref. [11]). Further adding to the benefits of such system is the increased training effectiveness that could be concluded (Ref. [4]).

The F-35 programme remained interested in the evolution of ECATS during its development and experimentation and requested to implement a demonstration of the multi-ship concepts. This demonstration was realised by means of integration in another NLR fighter simulator: Fighter 4-Ship (F4S) (Ref. [5]). After this demonstration ECATS attained a technology readiness level that led to the contract for Dutch Space and NLR to productise ECATS for integration in the overall F-35 ET concept (Ref. [8]). As such, ECATS matured over the years from a single ship system into an enhanced synchronised multi-ship system.

2.2.2 R&D history of LVC

There is a significant history on LVC related R&D at NLR and Dutch Space. Besides ECATS as a prime example of Live-Constructive integration there is also a long list of involvement in the development of interoperable virtual and constructive simulation. In recent years true LVC has been realised with The Netherlands armed forces.

Research on networked simulation, integrating virtual and constructive simulations in distributed environments, dates back to the mid 1990’s taking up speed in the 21st century. Various national and international research programs have been executed which revealed insight in issues, limitations, and how to tackle them. Most if not all of the challenges encountered in such distributed mission simulations are also encountered in LVC exercises, often even getting more pronounced due to more limiting networking means.

Some relevant networking limitations are:

- Bandwidth: network bandwidth is generally much more constrained on highly manoeuvrable platforms and systems.
- Latencies: latency is mostly directly correlated to communication distance; large latencies can cause significant time delayed observations of a shared scenario if not corrected for.
- Reliability: packages of information that are communicated over a network can be lost; there are communication protocols to overcome reliability issues but these protocols consume extra bandwidth and induce extra latency.
- Availability: the availability of a network is often constrained by geo-location and/or reach.

Networking is not the only concern for interoperability; security is a general concern applicable to all forms of interoperability especially in international settings. Avoidance of security issues often results is a degradation of ‘fair play’. Nations are often not willing or prohibited from sharing performance data of weapons, systems, and platforms. This is often circumvented by either:

- Agreeing on performance data, which has the distinct issue of having impact on tactics and thus the induction of negative training;
- All participants calling ‘kills’ by their own rules, which obscure any ‘fair play’ considerations.

Adding simulated platforms and systems to exercises introduce some specific semantic concerns that are not applicable to pure live training. A simulation is by definition a device represents an abstraction of a real-world live platform, system, or weapon. As such simulations will never exhibit 100% fidelity and can vary largely in fidelity depending on the intended use of such simulation. Again also security comes into play as fidelity of simulated models is often reduced due to security classification. Variance in fidelity can cause significant ‘fair play’ issues; this is true for both DMS as well as LVC.

The current state of affairs on LVC activities in The Netherlands is that NLR is actively involved in contributing to a national MoD concept development and experimentation (CD&E) exercise. In this exercise a Joint Common Operation Picture (JCOP) is created using data from simulators as well as live systems. For this purpose one of the research fighter simulators (F4S) is integrated into this exercise through a connection with the fighter command and control systems. Furthermore, also for this exercise the operator station of an experimental Unmanned Aircraft System (UAS) simulator is integrated with NLR’s own research aircraft that can as such operate as a UAS player with the safety of having in-aircraft pilots controlling the plane. In a related programme the transition from DMS R&D to implementation in The Netherlands armed forces is performed under the name Orange WAVE (Warfighter Alliance in a Virtual Environment).

2.3 Summary of ECATS benefits

Technical, training, and economical benefits of ECATS have been described in other publications (Ref. [4] and [11]). A short summary is presented here for the reader.

Operational benefits are gained by having the capability to use the system anytime anywhere without need for range or 'red-air' flights to perform:

- Air Missile Defence training and
- Counter air training.

More detailed operational benefits have been have been analysed for the RNLAF training programs and are reported in more detail in (Ref. [11]). This paper also describes cost/benefit of ECATS in detail.

Although ECATS can operate all by itself, either in single- or multi-ship mode, it can also be integrated with Autonomous Air Combat Manoeuvring Instrumentation (AACMI) systems and ranges, having good synergy with LVC.

3 Embedded Training and LVC

3.1 A Technology Perspective

As one moves away from the natural scope of application for a particular technology the challenges become harder and the benefits compared to cost smaller. An ET application like ECATS fits naturally in individual and team-training, scaling well to inter-team training potentially also Joint teams from different forces. Scaling of ET technology depends heavily on data-link technology.

Scaling of ET as a standalone technology beyond inter-team level is less opportune due to the fact that for operations level training there is normally a ground based coordination cell involved. Availability of the necessary data link also makes integration of ground based constructive simulation and addition of virtual simulators attractive, thus upgrading to a full LVC capability.

The technology to support ET and LVC aboard platforms is very similar, so much that at a functional level, support for ET can be regarded as enhanced support for LVC. The main components of a multi-ship ET application are: a data-link, an interfacing protocol, a constructive simulated scenario, and virtual ownship sensors, weapons, and counter measures. To support LVC on a live platform it will require all of these ET components except for the constructive simulated scenario, although also that component can be used to optimise the LVC support as will be explained next.

A shared challenge of ET and LVC is available bandwidth, reliability, and latency of data links to live platforms. Generally these data links are radio communication links that are more limited in bandwidth and have higher packet drop-out rates than land based networks. The ECATS ET application uses advanced techniques to minimise bandwidth usage and adverse impact from information drop-out and latency. The applied techniques are in line with, but a step up from the techniques generally in use for typical High Level Architecture (HLA) (Ref. [2]) and Distributed Interactive Simulation (DIS) (Ref. [1]) based Distributed Mission Simulations (DMS). Making use of the techniques that are already available from the ET integration also lowers the requirements on data links in an LVC environment.

One of the distinct advantages that a fully integrated ET/LVC solution brings to the table is the ability to distribute the constructive scenario simulation. In mission and scenario preparation it is often already clear which entities are going to heavily interact with each other. By simulating constructive entities as ‘close’ as possible to the live platforms they are going to interact with bandwidth can be reduced significantly as those LVC participants that do not have direct interaction will generally require lower update rates.

As such having a suitable ET application available on a platform is the best basis for integration of the platform in an LVC environment. At a functional level an ET application like ECATS provides all the functionality to a platform/system for integration in an LVC environment; the integration effort is thereby reduced to a data-link and network routing level. Merging ET and LVC in a single solution on a platform will provide a basis for flexible usage in various settings and scenarios.

3.2 A Training Perspective

Most operations, especially for smaller countries, are conducted in a combined multi-national setting. Furthermore, the different forces are able to collaborate much more effectively in joint operations with the help of modern technology. This modern operational situation contrasts to the setting two decades ago and requires much more flexibility of the military forces, the technology, and above all the personnel.

Training to these changed conditions, where it is sure that the operation of today will be different from the operation of tomorrow, is challenging. ET, DMS, and LVC are among the new means to provide training that have been developed to cope with these changing training requirements. This paper will not discuss live versus virtual training per se. A significant amount of training can be performed by pure virtual and/or constructive (VC) simulator training, however training with the real platforms and systems will of course remain essential in the overall training curriculum.

As has been discussed, from a technological point of view ET and LVC integrate very well and when an operation platform provides for both ET and LVC in an integrated configurable application most benefit can be gained from these technologies for training. LVC architectural development already is largely focussed to use DMS standards (Ref. [6]) thus with integration of ET and LVC all three technologies line-up to provide training in any desired configuration (taking into account the considerations at the semantic level due to simulation fidelity and network availability & capability (Ref. [7] and [10])).

Pure ET solutions require inherently less logistical preparation than LVC applications. An ET training solution like ECATS does not require a special infrastructure and integrates smoothly into the existing mission planning, briefing, execution, and debriefing cycle. In contrast LVC requires infrastructure to connect live forces with virtual and constructive simulations located elsewhere. Having available a configurable LVC capability which can operate as an live constructive ET application in ‘LC mode’ can provide the user with the full scale of training capabilities, from small scale individual training to large scale training of operations:

- Individual training: in LC/ET mode individual training can be supported in a variety of training scenarios, e.g.: Surface to Air Missile (SAM) defensive tactics, weapon release procedures, operation of aircraft equipment.
- Team training: also in LC/ET mode tactical team training of counter-air, air strike/interdiction, or suppression of enemy air defences (SEAD) missions can be performed (Ref. [8]).

- Inter-team training: in LC/ET or full LVC mode multiple teams can perform coordinated missions in a single training scenario. Depending on the connected systems and platforms virtual simulators can be integrated into the training.
- Operations training: full LVC is generally desired for this larger scale training (if not performed purely as a live exercise). Large scale exercises can set-up with a mix of live systems and platforms, virtual human operated simulators, and a potentially very large amount of constructively simulated participants.

Since training at larger scale is done less frequently than training at individual and team levels, and the fact that operations (and inter-team) training requires more infrastructure due to size of the exercise, the overhead of a full scale LVC infrastructure is not a significant factor for larger scale training. However for day to day training at individual and team level a live constructive ET capability provides the most efficient training functionality for training on a live platform. And as stated earlier, from a technological stance availability of such ET capability facilitates integration of a full LVC capability.

4 Concluding Remarks

There are several reasons why LVC without an advanced ET capability like ECATS can never reach the full training potential of having both in synergy. An ET application has the distinct advantage of requiring almost no specific organised infrastructure to use it. When using ECATS it merely requires the selection/creation of training scenarios which would of course also be required for an LVC training. ET training can be performed easily anytime anywhere and with a library of training scenarios available the setup of such ET exercise can be fully and smoothly integrated into the regular mission planning, briefing, execution, and debriefing cycles. There is no limitation to certain training areas; there is even the possibility to use ET while stationed in an operational area to limit the loss of full mission readiness of pilots that are active in an operation.

On the other hand an ET capability is generally more limiting in scope, in the sense that an LVC solution with ground/air data links is better suited to training exercises with a scale beyond inter-team training. As has been shown in this paper, ET technology and LVC technology are a natural fit and ET technology enhances LVC integration on ET enabled platforms. The availability of an advanced ET live constructive capability means that there is an opportunity to alleviate some of the challenges encountered by e.g. bandwidth limitations of ground/air data links.

As a conclusion it is stated that advanced ET applications like ECATS are enablers for successful LVC applications. Blending LVC and ET presents opportunities to flexibly scale training application from individual training to large scale (air) operation and joint training exercises with the most effective use of scarce resources.

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