LVC for Joint and Combined Air Power

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ABSTRACT

LVC incorporates Live, Virtual and Constructive elements into one training environment. Conducting seamless LVC exercises remains one of the most challenging issues of Modelling and Simulation for modern Air Forces. There is a lack of interoperability, limited reuse and loose integration between the Live, Virtual and Constructive assets across multiple simulation and training environments. NLR is conducting a research program which focusses on efficient and user-oriented LVC concepts for training in the Air Domain.

This paper will explain the program's research activities and efforts, which focus on developing knowledge regarding a number of specific topics: training, architectures, technology, operations, and experimentation. A concept for a large LVC exercise, involving a total war scenario divided into three smaller missions, has been designed to frame the research topics and will function as a stepping stone for the design of a full Air LVC training concept. Moreover, an initial explorative experiment aimed to evaluate the benefits of the LVC concept as well as identify the possibilities and limitations using currently available assets and technology is described. Finally, the paper describes the main technological, architecture, and training considerations regarding the implementation of an LVC environment.

1 INTRODUCTION

The Royal Netherlands Air Force (RNLAF), like many other NATO Air Forces, are currently integrating a number of new modern weapon systems in their operational fleet, like the F-35, MQ-9 Reaper, Apache AH-64E and Chinook CH-49F. These modern systems provides the RNLAF with opportunities to respond in a more agile, adaptive and flexible manner to new operational scenarios. The RNLAF must be capable of adapting to threats and crisis situations rapidly, scaling up or down quickly, and taking a customised approach. There will be a shift to Multi-Domain Operations (MDO), operations in a contested environment and information-driven operations [1]. This requires an adjustment of the current live and virtual training of our fighter pilots and air system operators in order to prepare them in an efficient way for operating the new generation of systems. To facilitate those types of training, environments are needed that enable and support complex execution of advanced tactics. Such environments should include operationally relevant scenarios that incorporate the stimulation and usage of advanced mission systems. This could be accomplished through the use of interoperable and open architecture Live, Virtual and Constructive (LVC) solutions applying standardized LVC technology and data standards to the maximum extend.

An LVC environment is a concept where Live, Virtual, and Constructive entities can interoperate with each other to generate operationally realistic scenarios for training and experimentation. Within that context, the Live environment is defined as real people operating an actual operational weapon system in a typical combat scenario. The Virtual environment is defined as real people operating a simulated (weapon) system, i.e. a fighter pilot in a flight simulator. The Constructive environment is defined as simulated people operating simulated systems, e.g. Computer-Generated Forces (CGF) used to enhance the training environment. These simple definitions bound the scope of LVC operations, but are often misconstrued resulting in confusion. For purposes of this discussion, the Live environment is the focus of the training scenario, and must be present for LVC to take place. Although valid training may occur in the Virtual environment as part of LVC operations, it cannot be the focus of the training. Therefore, training that only includes the Virtual and Constructive environments should not be called LVC simply because V and C environments are present. The VC configuration has existed for long time and is called Mission Training through Distributed Simulation (MTDS) [2] or Distributed Synthetic Training (DST).

2 THE POTENTIAL FOR LVC TRAINING

There is currently a growing trend away from live air training towards apparently less expensive mission training through simulations. In fact, already in 2011 a RAND report [3] stated that shrinking resources and expanding mission requirements jeopardize the ability of the US Air Force to meet proficiency standards to accomplish wartime missions. Data compiled by RAND indicate that the high costs of training are largely driven by the need to field red forces and is further compounded by the need to ensure that these red forces are effective training adversaries. Experts argue for an increased use of DST and LVC training as a means to reduce training costs. Furthermore, the RAND report concludes that "in the long run, development of the LVC ability to inject simulated and constructive threats into live aircraft may be the only fiscally responsible approach to improving training". The findings of the RAND report are explaining the situation for the US Air Force, however the findings are exemplary for any modern Air Force.

Nonetheless, cost savings are not the only reason; especially with the large footprints of modern sensors, networks, and weapons can specific missions simply not be efficiently and safely trained in a real environment due to limited airspace available for training and environmental restrictions (e.g., noise, or carbon emissions). Also availability of material (e.g., aircraft, threat systems, or instrumentation and personnel (i.e., pilots and support personnel) is nowadays a challenge for Air Forces. Simulations seem to be the general solution to address this issue. However, fighter pilots cannot achieve the required operational readiness levels in flight simulations only, and there is no advocacy towards zero flight time training for military pilots. The physical and emotional aspects of military air operations cannot be compared to the airline operations for which live training is no longer required. Thus making the combination of both live and synthetic training is potentially an ideal solution to these issues.

With respect to training, what distinguishes LVC from MTDS or DST concepts is a specific emphasis on the integration of live platforms. The use of integrated live, virtual, and constructive systems for training is expected to provide a range of benefits [4]:

1. Enhancing the training outcomes obtained from live flying,
2. Enabling the generation of scenarios of sufficient scale and complexity to exercise fifth-generation capabilities fully,
3. Augmenting existing training ranges with electronic and cyber warfare effects,
4. Better supporting the large footprints of modern sensors, networks, and weapons, and
5. Allowing new platforms to be exercised in a secure environment so as not to reveal the sensitive aspects of their capability.

LVC environments promise thus opportunities for increasing training efficiency and effectiveness for the Joint and Air domain, but while novel technology and the use of it offers new opportunities, it also poses new challenges.

3 THE LVC RESEARCH PROGRAMME IN THE NETHERLANDS

In 2021 the Royal Netherlands Aerospace Centre (NLR) initiated a research program under guidance of the RNLAF focussing on LVC. The research program's goal is to develop knowledge about LVC regarding a number of specific topics, namely: training, architecture, technology, operations and experimentation. Topic-specific knowledge, processes and technology - so called building blocks - will be combined in an overarching Air LVC concept. Building blocks can range from complete systems, such as flight simulators, training pods or datalink terminals, to smaller tools and services, such as datalink gateways or weapon effect services. Based on those, an LVC solution architecture will be determined and used to implement a specific air domain LVC capability consisting of existing systems, networks and tools. Subsequently, this capability can be used to test and evaluate the LVC technology building blocks and processes in relevant (international) operational exercises.

3.1 Innovative LVC Concepts for Training

The RNLAF is undergoing a transition towards a 5th generation Air Force, which is highly technical, flexible in its deployment, and can be operate both independently and in joint and combined missions. This requires new and innovative training concepts, which focus on 'train for the unexpected' where LVC technologies are foreseen to be one of the predominant approaches to facilitate training. Training concepts in general also move towards performance based training where training scenarios are tailored to the individual's specific training needs so that the training maximizes training value to the trainee. Performance based training requires a learning ecosystem – the collection of techniques, components, methods, and training organisation – that records, stores, and analyses much data of both individuals and teams.

A well designed LVC-environment – one where live players can interoperate with the synthetic environment as they would normally with other live entities – can support a learning ecosystem and performance based training in several ways.

The first benefit of an LVC environment is that it is scalable. The synthetic environment is not as limited by geography, air space or number of entities as live exercises are. LVC can facilitate training tasks aimed at the individual trainee, large exercises and everything in between. LVC can be used for individual training (e.g., JTAC), team training (e.g., four-ship strike team), or collective training (e.g., large joint and combined exercises). Secondly, LVC offers flexibility in that setting up scenarios in the synthetic environment is relatively easy compared to preparing and executing a live exercise. The result is that it hardly matters whether a trainee needs to experience a complex scenario with many entities or a simple one with only a few. Preparing the scenario should not be the bottleneck any longer, meaning that scenarios can be flexibly designed to fit the purpose of the trainees. Moreover, live and virtual entities could be exchanged without much difficulty. This would be especially beneficial when, for example, weather or a break down grounds a live platform, as the grounded player could still participate in the exercise as a virtual entity.

For training experts the challenge lies in finding a good trade-off between live and virtual training. Live training offers training value that virtual training cannot achieve and vice versa. LVC practically allows endless combinations and numbers of Live, Virtual and Constructive entities to be included in a training scenario. Here we can distinguish between primary and supporting positions. The primary position fulfils a training objective or is crucial for operational purposes. Supporting positions do not have a crucial role, but they are required to comprehensively perform the exercise. The primary positions are mostly live or virtual, supporting positions are mostly constructive or virtual. The different positions require different approaches on how to determine the entity state and the device that is used. Selecting the right combination and the correct scenario could be supported by smart algorithms and Artificial Intelligence (AI) technology. Another aspect is how to reflect and evaluate on the training. The training value needs to be measured in order to conclude what the effect was of the training. Therefore it is important to point out which data, metrics and instruments are needed to determine the training value. These should then for all entities in a LVC exercise be aggregated in the synthetic environment, so that this data could be recorded and analysed to facilitate performance based training. With that an LVC environment would become a cornerstone of the future RNLAF learning ecosystem.

3.2 LVC Architecture and Technology

One major challenge in the area of LVC architecture and technology is to combine existing simulation and operational solutions into a single environment where live and synthetic entities reach (at least) a semantic level of interoperability. Many standards, protocols, and reference architectures have been developed in the distributed synthetic trainings domain, like the DIS [6] or HLA [7] standards and the MTDS reference architecture [8], that facilitate interoperability between synthetic entities. Alternatively, there are many operational systems that facilitate data exchange between operational platforms, like the tactical datalink Link-16, that are typically also standardized.

The first challenge for M&S specialists lies in integrating the various standards that are used for data exchange in synthetic and live environments. Technical solutions, like gateways which allow data from different standards to be exchanged exists, but these tend to be one off solutions. For future LVC-environments to be easily employed and to facilitate exercises on a small and large scale and in various scenarios, standardization of the gateway technology is required. Note, that this is does not argue for an entirely new LVC standard to perform exercises in, but a standard to define how different protocols and standards should exchange data.

Another challenge is that there is a discrepancy between operational datalink system and the synthetic environment on a syntactical level of interoperability. Operational datalink systems can typically only send and receive tactical data – like PPLI (Precise Participant Location and Identification) or radar tracks – whereas synthetic environments also utilize simulation data – like detonation events or simulation management data. That is, the live platform and synthetic environment are able to exchange some data, but not all. For example, Link-16 could receive radar tracks of constructive red forces generated on a remote server as if another aircraft has perceived them, but cannot receive data that simulates the radar itself. Hence, the level of interoperability a datalink offers depends on the type of data that needs to be exchanged. This does not mean that operational datalinks cannot be used for LVC purposes. On the contrary, operational datalinks can be the stepping stone to realising a fully integrated LVC training environment, as they are an relatively cheap and easy way to implement LVC technology into an existing training environment, albeit with imitations. These limitations, if understood well, can be handled so that LVC offers training value. In section 4.3. an example is provided how an LVC environment using an operational datalink and voice communication can be created, in a so-called minimal viable exercise, which is believed to achieve training value for a live pilot.

Nonetheless, to achieve a pragmatic level of interoperability (or higher) dedicated dare required. This would require substantial research and development efforts as the operational platforms would need modification to facilitate a dedicated training datalink. Additional fast and high throughput data communication capabilities are needed to handle training data exchange. There are developments in this area already, as training pods exist which can be mounted on an aircraft's hardpoints. For example, the Fifth Generation Advanced Training Waveform (5GATW) developed by SLATE, which can achieve high throughput of data between LVC entities [9]. Also, the aircraft's Operational Flight Program (OFP) would need modification to allow the integration of training data into the platform's systems, especially considering safety issues. For example, there could be serious safety concerns in live aircraft when pilots are so immersed into a synthetic environment that they lose situational awareness of reality.

However, if a fast and high throughput connection between live and the synthetic environment can be achieved, many more modelling and simulation issues would need resolving for an LVC training environment to be effective. For example, which standard is used for data transmission over the dedicated training data link d and where are computer generated forces and weapon fly-outs modelled (e.g., remotely, on land based servers, or locally, in dedicated aircraft systems); or how does the system handle a connection time-out? One area that is actively investigated is the reduction of required bandwidth for dedicated training datalinks. C-DIS, for example, is a compressed version of DIS [6], which utilizes less bandwidth than the original version. It achieves this reduction by sending only partial or lower resolution DIS Protocol Data Units (PDUs). Test have demonstrated a reductions up to a factor 6, depending on the size of packets sent [10].

In summary, design choices affect the among others required bandwidth for the datalink technology and could affect an LVC's environment's training value. Apart from the technical issues that need to be resolved there are many modelling and simulation questions which need answers for LVC to facilitate successful training.

4 LVC USE CASES

The goal of the research programme is to obtain the required knowledge in order to set up an LVC infrastructure for training and Concept Development and Experimentation (CD&E) purposes. As an starting point of the study and to provide context to the research questions a use case has been identified. This use case has been specifically designed for the Royal Netherlands Air Force (RNLAF) and will set a base for the study on the operational aspects of an LVC program. In addition, the use case will be used as a framework for the entire research project in order to answer specific research questions and create a clear context to communicate between the different research strands.

4.1 Design Philosophy

Frisian Flag is a well-known exercise with an international character, realistic 5th Generation scenarios, presence of supporting assets and a large role for the F-35. That makes this exercise an excellent base for the design of the LVC use case. By enriching this exercise with LVC capabilities, the RNLAF can aim to increase effectivity of the exercise to a larger extent by adding more/effective platforms to achieve better trained military personnel. The full scenario has been designed with a focus on a joint and combined mission (see Figure 1) which is in line with the Netherlands Ministry of Defence vision for 2035 [5].

Organizing an LVC flag exercise would occur occasionally and requires a substantial investment of money and time, while LVC-technology can also support day-to-day training exercises. Therefore, a day-to-day training exercise has been designed which enhances the scenario with virtual and constructive entities. A day-to-day training exercise is an exercise in which less platforms are used, which can be fully operated by the members of a squadron and is organized and operated on the same location. This day-to-day exercise will be used to examine LVC configurations that are less demanding on technology, coordination and infrastructure and still add training value. Because there is a large difference between a distributed full scenario and a co-located day-to-day training exercise, a categorization has been made. The categorization is based on the training task (see **Table 1** for definitions) and the location of the team members respective to each other (co-located versus distributed). Many of the research questions formulated in research programme are dependent on the exercise category, making the distinction convenient to delineate a study's focus. One can, for example, categorize an exercise as a "distributed limited whole task LVC" exercise.

Table 1 Definitions of training tasks

Concept	Definition
Part task	Day-to-day squadron training, focus on skills only, e.g. making turns or applying communication protocols.
Limited whole task	Day-to-day squadron training, procedural training, training focus on skills and procedures, not combat orientated, white cell not required
Small scale whole task	High end day-to-day training, internal coordination required, squadron white cell provides scenario, combat orientated training mission in a tactical vacuum
Medium scale whole task	Small Combined Air Operations (COMAO), limited amount of formations involved, less entities than large scale whole task, coordination required, limited white cell required
Large scale whole task	Complex COMAO, large amount of forces, lots of coordination involved, full white cell required

4.2 Whole Task Use Case

A single LVC scenario (large scale whole task) has been designed to train a total war scenario against a near peer adversary in a joint and combined environment. The exercise is suitable for questions like:

- What kind of tooling does one need to organize LVC exercises of this scale?
- How does a white cell operate during LVC exercises?
- What are the requirements to join international LVC exercises?

The scenario can be divided into three subcases, which can also be executed individually if the entire scenario is too extensive (i.e., aircraft and personnel intensive), or if the deliberate choice is made to train/evaluate a selective set of operators or concepts. These smaller subcases are suitable for questions like:

- How does one deal with Cross Domain Security (CDS)?
- What kind of CD&E facilities does one need?
- What kind of datalink possibilities are present?
- How can we optimize training value for specific participants?

In Figure 1 the big picture of the use case is presented. An initial allocation of Live, Virtual and Constructive elements has been carried out, and the results are included in this figure by circles with an L, V or C above each entity. This allocation is not immutable, but by carrying out an initial allocation a feel is created for the available options. In the figure the blue symbols indicate friendly forces, the red symbols indicate enemy forces, and the red curved line indicates the Forward Line of Own Troops (FLOT). The goal of this exercise is to train an offensive, joint and combined scenario.

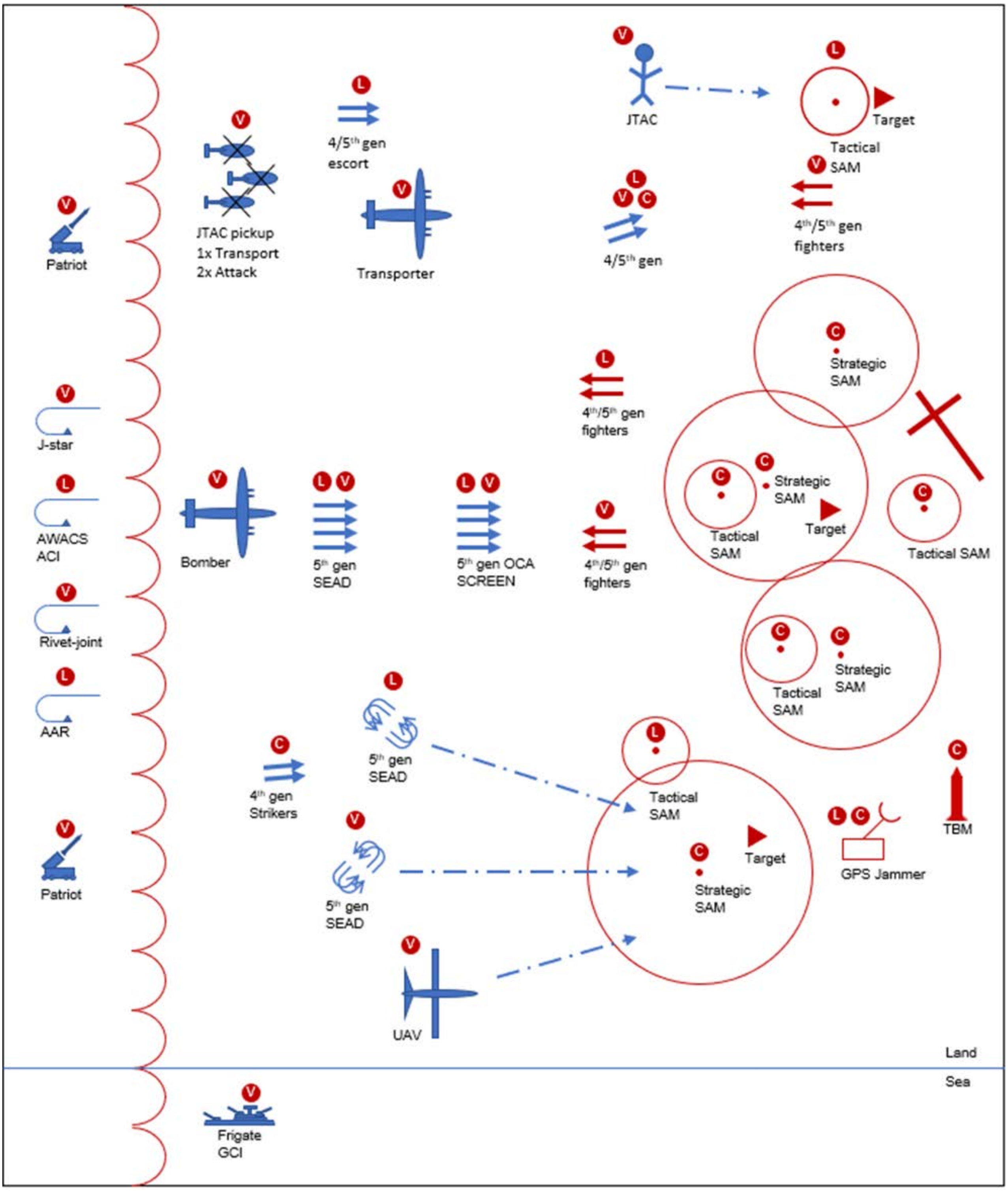

Figure 1: Visual representation of the complete use case

4.3 Minimal Viable LVC exercise

F-35s have an Embedded Training (ET) module onboard which can be used inject scenarios with constructive red air or ground threats. Complementing such and LC-scenario with Virtual entities can adds training value to the pilots as they need to coordinate and communicate with other blue air entities outside their fighter group. To investigate this within the research program a so-called Minimal Viable Exercise (MVE) will be performed to show how with minimal development effort an LVC environment can be created that offers additional training value to a pilot in a live aircraft, compared to training exercise in either a live or synthetic environment. The MVE scenario shown in Figure 2 consists of:

- Four live F-35s, tasked to supress the enemy air defences and offensive counter air. They are to clear the way for the striker team that follows behind;
- One or two F-16s, tasked to strike the strategic surface to air missile (SAM) site;
- Two constructive red air 4th or 5th generation fighters;
- A constructive strategic SAM site; and
- A constructive tactical SAM site.

The architecture of the MVE is shown in Figure 3 and consist of the following components and connections:

- Live F-35s with an ET-module that generate the constructive red forces and communicates via a proprietary datalink.
- A MIDS-terminal to facilitate communication between the live and virtual entities via a Link-16 datalink.
- A synthetic environment consisting of a F-16 simulator which communicates over DIS with a gateway that connect to MIDS-terminal.
- A gateway that translates DIS packages into the Platform Delta messages which can be received by the MIDS-terminal. Platform Delta is the MIDS interface protocol for ethernet connections.

Note that in this scenario only PPLI-messages and voice are communicated between the live and virtual entities, which is adequate to facilitate the training. Future experiments will also investigate the exchange of other messages types, which can currently not be exchanged as a result of a difference in Block Upgrades between link-16 terminals.

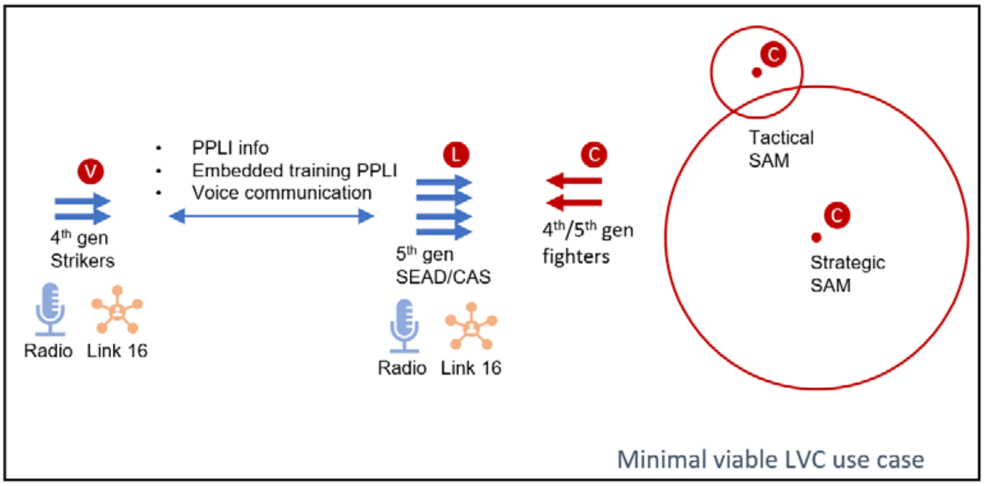

Figure 2: Illustration of the scenario for the Minimal Viable Exercise.

During day-to-day training a squadron is usually restricted to a certain limited number of live assets. For and offensive counter air suppression of enemy air defence (OCA-SEAD) mission they are typically dependent on other units or Embedded Training (ET, i.e., constructive red air) modules to provide enemy threats and a friendly force strike package. ET module cannot realistically simulate blue strikers as they cannot communicate verbally and do not anticipate or adapt to unexpected changes in the scenario.

The MVE addresses this issue by linking a virtual F-16 softpit (i.e., desktop simulator) via a Link-16 tactical datalink and voice communication to live F-35s. The live pilots can interact with the virtual player through voice communication, which adds training value compared to training in combination with an ET-module alone.

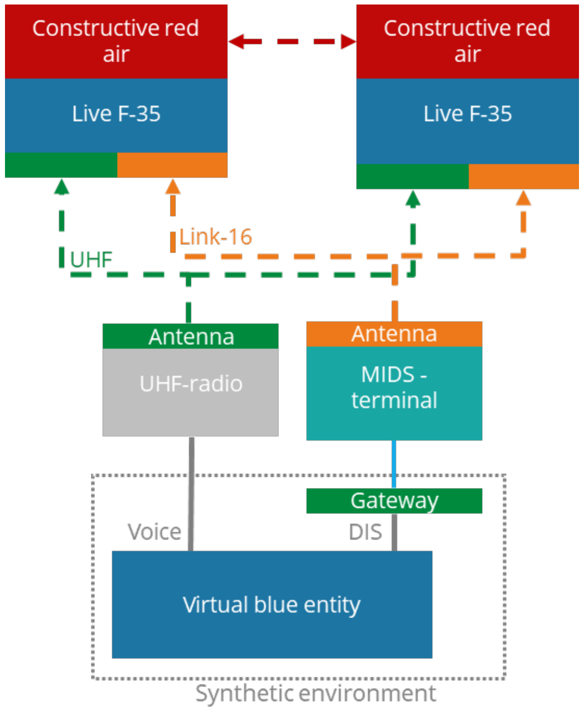

Figure 3: illustration of the architecture for the Minimal Viable Exercise.

Linking a live platform via a tactical datalink to an synthetic environment has been accomplished before and therefore from an technological perspective not particularly innovative. However, the MVE is meant to function as a stepping stone for future research within the program. In that regard the goal of the MVE is two-fold: 1) to demonstrate that with minimal effort LVC can enhance live training and to convince training experts within the RNLAF that LVC is worth investigating further, and 2) create an initial testbed which can be expanded upon in future experiments.

5 INITIAL RESULTS AND WAY FORWARD

The use case is primarily based on the Netherlands Defence vision 2035 ('Defensievisie 2035') [5] and illustrates the LVC potential for future training. The use case will be used for reference when considering questions related to optimization of training value, identification of architectural solutions and operational consequences if an exercise like this is organized in the future. The choices made with respect to allocation of assets to either L, V, or C can be seen as a particular instantiation (the intuitive one) of many possible allocations.

The training research in our programme will focus on providing a conceptual framework and the means to determine the most appropriate allocations in view of potential training value taking actual training needs of aircrew into the equation. It will perform research how to measure training value and investigate to what extent the mix of Live and Virtual players influence the way to monitor performance. From an architectural perspective the use case will be utilized to create an overview of the data that is transmitted between LVC elements, with the intention to estimate the requirements for the LVC network capabilities and the data link technologies. The research will predominantly focus on integrating legacy systems with all their communication limitations, in order to realize quick wins and create a stepping stone for an LVC capability in the Netherlands. The operations research track intends to identify which operational tasks need to be fulfilled to organize such LVC exercises with respect to the set-up of the training white cell, location of simulation systems, requirements to operators, and required flexibility and adaptability of the exercise.

The MVE (see section 4.3.) will be an initial experiment in which live F-35s will be connected to a synthetic environment through a Link-16 tactical datalink. This set-up is deliberately kept simple and will demonstrate the additional training value an minimal LVC environment can offer and will create the initial testbed upon which future research within the program will be based.

Finally the paper describes the main technological, architecture, and training considerations regarding the implementation of an LVC environment. We believe that LVC technology has many benefits and can support new innovative training approaches, but what that solution specifically looks like is unclear. LVC is multidimensional problem that needs to take into account all the considerations described in this paper, and more. The presented Dutch LVC research program, executed by Royal NLR, is actively contributing in shaping the future LVC environment and will continue the following years. Not only on a national level, but also looking for cooperation with international players to look for an optimal LVC solution where partner nations can train their operational warfighters in multinational, collective training exercises.

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