The Potential of LVC for Creating Air Power - Beyond Adversaries

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ABSTRACT

Full-scale live training is increasingly hampered by a variety of new demands and restrictions. Training in simulation-based environments accommodates some training needs that cannot be realised in the real world but live training remains essential for a balanced training program. LVC - incorporating live, virtual and constructive elements into one training environment- may relieve some of the demands and restrictions for live-only training. However, conducting seamless LVC exercises remains one of the most challenging issues of Modelling and Simulation for modern Air Forces.

Currently 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 therefore conducting a research program which focuses on efficient, scalable and user-oriented Air LVC concepts. 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 functions as a stepping stone for the design of a full Air LVC training concept. NLR is investing in knowledge and solutions regarding LVC training development, integrated service-oriented architectures, data link and communication technology and LVC exercise operations. Simultaneously NLR, in close cooperation with the RNLAF, is incrementally developing a conceptual LVC capability for air operations by implementing practical use cases aligned with operational training exercises. In October 2023 a synthetic environment – consisting of a virtual fighter and constructive entities – was integrated into the large-scale live exercise Frisian Flag. This provided NLR with the unique opportunity to investigate LVC in a real-life exercise and shows how small technological advancements can yield a significant impact on training.

This paper identifies the possibilities and limitations using currently available assets and technology and determines the main technological, architecture, training and operational concepts considerations for a future LVC environment.

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INTRODUCTION

The geopolitical situation is seeing drastic changes in the current day and age. Tensions between (near-)peer adversaries are becoming a reality after decades of more asymmetrical conflict. On the other hand, next generation platforms and weaponry result in advanced means of defence and deterrence. Specifically in the air domain, the introduction of 5th generation platforms yields a new era of how to conduct missions, driven by both the new capabilities and the increased threats. That has implications for the training infrastructure. The use of simulation has increased through Distributed Synthetic Training (DST) exercises, enhanced embedded simulation technology on board of live assets, and (limited) interoperability between ground simulation and live systems. But the Virtual and Constructive components added to Live exercises mainly provide for adversary elements. Also, the simulation facilities and its joint infrastructure DST are not yet mature. There is no debate that even a fully mature DST would replace all live training. There will always be a need for live, complex training. The requirements for live training have grown as well to the extent that, for most air forces, relying on live training alone is no longer an option. Live, complex training has to be combined with powerful simulation, from on-board simulation to DST facilities.

An LVC environment is a concept where Live (L), Virtual (V), and Constructive (C) 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 a mature LVC infrastructure could facilitate training with only virtual and constructive elements, such training should not be called LVC simply because V and C environments are used. The VC configuration exists for long time and is called Mission Training through Distributed Simulation (MTDS) (Lemmers, Hemmings, and Swindell, 2020) or Distributed Synthetic Training (DST).

In 2021 the Royal Netherlands Aerospace Centre (NLR) initiated a research program under guidance of the Royal Netherlands Air Force (RNLAF) focusing on efficient, scalable and user-oriented Air LVC concepts. NLR is investing in knowledge and solutions regarding LVC training development, integrated service-oriented architectures, data link and communication technology and LVC exercise operations. 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 data link terminals, to smaller tools and services, such as data link gateways or weapon effect services. Aside of knowledge development, NLR and RNLAF are incrementally developing a conceptual LVC capability for air operations by implementing practical use cases aligned with operational training exercises.

TOWARDS RADICAL FLEXIBILITY IN TRAINING

The potential of mature LVC is evident: training needs can be fulfilled faster and better in more realistic scenarios while restrictions of live training with respect to space, rules & legislation, and security can be met. Many training goals can be achieved as if the restrictions were not there. This generates higher training value, while enabling a range of exercises that may not have been possible otherwise due to unavailability of assets or personnel. Current training programs may be realised more easily. Here, LVC provides a supporting role in realising a training exercise that was designed originally for live-only training, given the training possibilities for a squadron in a certain time frame. However, new training approaches may be developed when a considerable number of virtual assets can be added to live training and especially when many realistic constructive components are available. With many constructive elements, both own force as well as opponents, just one team, for example a four-ship (live), may practice (parts of) a large scale exercise several times, given certain variation, for example building up in threat level.

This example demonstrates a new training possibility: a more personalised, flexible approach in achieving and maintaining readiness. Already in 2018 a RAND report (referred by GAO 2020) concluded that Ready Aircrew Programs often do not achieve their goals completely. A stronger information guided approach (proficiency based training) was advised in order to be able to make better assumptions for training programs. Keeping record of individual proficiencies on other than safety related skills in continuation training is new to the pilot community and requires substantial data logging and more advanced readiness analytics to succeed. But the resulting detailed personal training needs enable deeper insight in the total training needs of a squadron, and a more accurate determination of training capacity needs while scheduling increases in flexibility. Initial modelling for this concept has been reported by Fjarbu et al (2020). Such a training concept provides new possibilities for LVC training, but the concept itself also needs an LVC infrastructure with abundant supply of either live, virtual and constructive elements, in order to reach its full potential.

When combining a mature LVC capability with a proficiency based approach, an increased level of flexibility becomes available, especially in continuation training. The traditional building block principle may be applied for individuals where needed (also using simulation only -VC- training), but an individual training need will no longer interfere with the needs of a squadron as a whole or the needs of other individual pilots. Readiness is achieved more easily and can be managed proactively instead of reactively through advanced readiness analytics. These analytics generate individual predictions of training needs, which would lead to a scheduling nightmare in the current approach. With a mature and large LVC infrastructure and an automated, continuous schedule optimizer, the effort of ops officers will shift from scheduling to gathering proficiency data. Overall planning and scheduling should be a matter of monitoring and making minor adjustments. Also, as a result of this highly adaptive training approach, a change in operational needs is much easier to accommodate.

This vision requires 1) considerable further development in intelligent, realistic behaviour of constructives, 2) to solve the technological challenges facing todays large scale LVC and 3) to develop robust infrastructures that also supports the recommended proficiency based approach (simulators, data links, performance/proficiency data gathering, schedule optimizers). We believe such developments benefit strongly from Concept Development and Experimentation (CD&E) in an actual training environment. This has guided our work presented in this paper.

A CONCEPTUAL LVC TRAINING USE CASE

The goal of the research program is to obtain the required knowledge in order to set up an LVC infrastructure for training and CD&E purposes. A 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. The 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.

Whole task LVC use case

As a starting point of the study and to provide context to the research questions a use case is identified. This use case is specifically designed for the RNLAF and sets a base for the study on the operational aspects of an LVC program. In addition, the use case is 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 topics.

A single LVC scenario (large scale whole task) is 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 can we optimize training value for specific participants?
- What kind of data link possibilities are present?
- How does one deal with Cross Domain Security (CDS)?

In Figure 1 the big picture of the use case is presented. An initial allocation of Live, Virtual and Constructive elements is 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) with a safe zone on the left side. The goal of this exercise is to train an offensive, joint and combined scenarios.

Large scale training exercise Frisian Flag 2023

For realizing training scenarios that cover the whole task use case an LVC training environment with a high level of interoperability is required. This environment needs a dedicated data link to exchange training data with a high throughput and low latency. Research and development regarding the standardization of such links and technology is ongoing, but it is unlikely that a highly interoperable LVC environment with all systems integrated through a dedicated training data link will become prevalent in the coming years. Fortunately, a fully integrated LVC environment is not required to enhance the relatively small-scale training scenarios which are typically used during day-to-day training. Using existing technologies and operational data links effective LVC training can be facilitated, albeit with a reduced level of interoperability and limited set of possible interaction between the entities. Training experts agree that even a slight enhancement of the live day-to-day training might provide relatively large training benefits.

A practical research experiment was conducted during the live large-scale exercise Frisian Flag 2023 (FF`23), where NLR (in collaboration with the Dutch research organization TNO) supported the RNLAF in a proof-of-concept for LVC over Link-16. During this exercise multiple squadrons from different nations prepare and execute training scenarios aimed to train planning, coordination, and execution of airborne missions. During FF`23 two types of scenarios are typically trained, namely Offensive Counter Air (OCA) and Defensive Counter Air (DCA). Figure 2 presents the basic OCA scenario on which the research experiment is based. The green circles (L) indicate the live entities, the yellow (V) indicate virtual entities, and the range (C) indicate constructive entities.

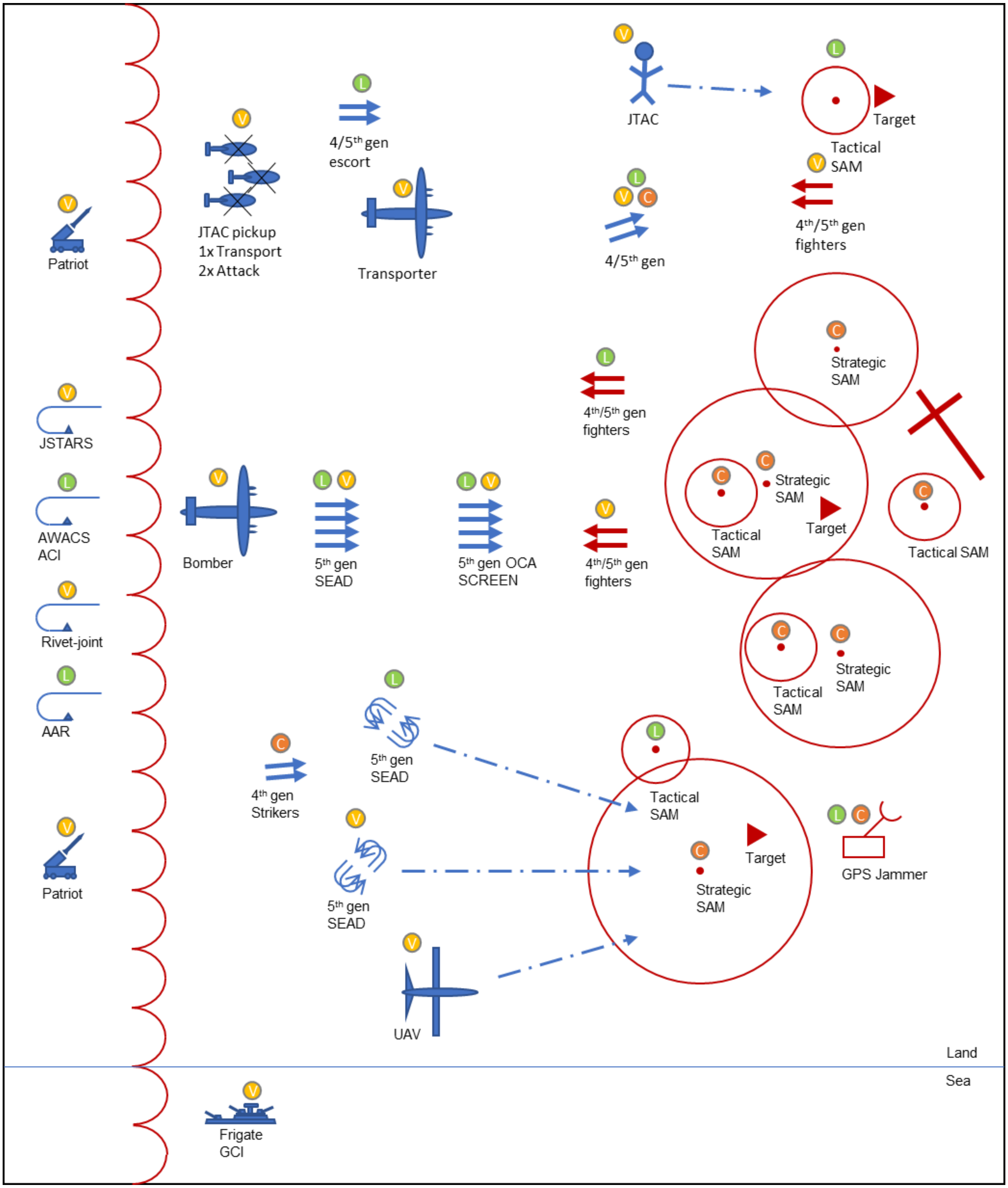

Figure 1. Visual representation of whole task LVC use case

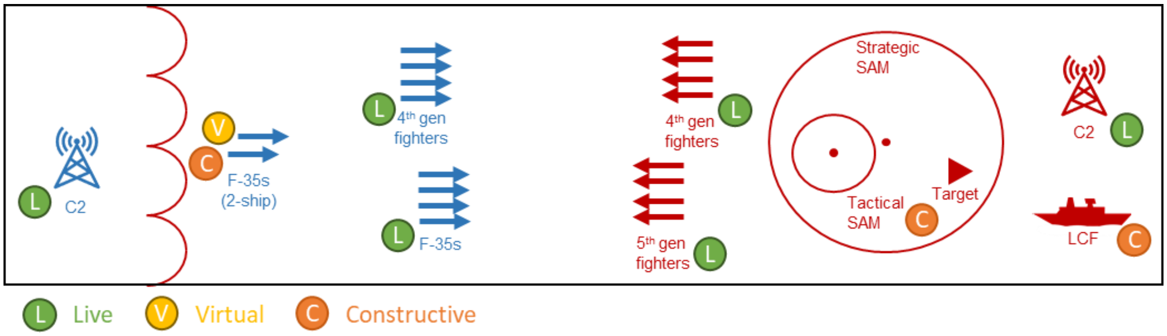

Figure 2. Basic OCA training scenario

The mission goal in the OCA scenario is to take out a ground target. The scenario is predominantly aimed at live training, meaning that the fighters and fighter controllers (C2) are live players. The F-35 2-ship is a virtual entity (i.e., simulator with live pilot) that is accompanied by a constructive wingman programmed to follow the virtual F-35.The live fighters engage the adversaries, while the virtual aircraft takes on the role of a bomber (i.e., a fighter with an Air/Ground focused weapon load). Live fighters focus on engaging the red air adversaries, while the bomber needs to stay out of the fight until it is safe to approach the target. On the red side the target and Integrated Air Missile Defense (IAMD) are constructive entities, as well as a frigate (LCF) which is used to the provide the position of the virtual and constructive blue entities to the live red fighters.

The main goal of the synthetic[1] players is to increase complexity of the scenario. Therefore, the training scenario is less focused on providing training value for virtual entities, as it will not engage the enemy air threats. The main reason it is present in the scenario is to increase complexity to the training for the live fighter pilots and fighter controllers by adding extra coordination and communication. Therefore, the bomber is assigned to be virtual.

LVC architecture during the FF'23 exercise

In Figure 3 the generic LVC architecture that is designed for FF'23 is shown. Essentially, it uses an operational Link-16 and UHF/VHF radio to connect a virtual simulator to live F35s, so that the live and virtual blue air players possess the same surveillance picture and are able to verbally communicate. The choice for Link-16 in FF'23 is straightforward, because it is the standard tactical data link used by the FF'23 participants and thus is available during FF'23. Link-16 is an operational tactical data link, which means that the messages that can be communicated over this network are standardized for operational use. Consequently, it is not able to communicate all messages which are typically needed in a simulated environment to facilitate a high level of interoperability. Gateways between the Link-16 terminal and the radio ensure the exchange of messages between the synthetic and live environment. Note that, for clarity the exercise control cell and the radio network of the red players are excluded from the figure.

[1] This study regards synthetic players to be both the virtual and constructive entities.

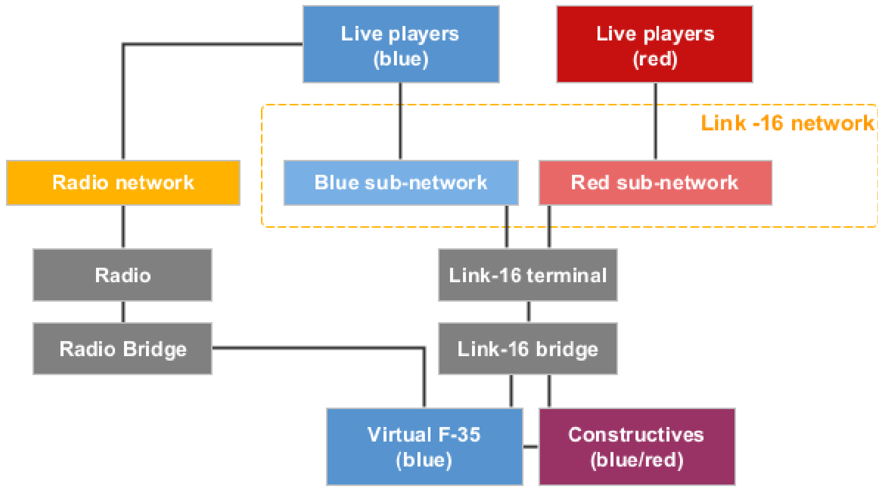

Figure 3. The concept LVC architecture for FF'23

The architecture consists of the following elements:

Live players – Red and blue aircraft and C2-cells connect via UHF/VHF radio and a Link-16 network with a separate blue and red subnet so each side has a separate surveillance picture at their disposal.

Virtual player – An Effects Based Simulator (EBS) is used to simulate the F-35. The EBS utilizes Distributed Interactive Simulation (DIS) standard (IEEE, 2012) to interoperate with the other synthetic elements in the architecture. The EBS uses DIS voice messages that are sent to the radio bridge for live voice communication with the live blue players. The EBS uses DIS SISO-J messages to communicate with the tactical data link network and sent these SISO-J messages to the Link-16 Bridge.

Constructives – A constructive threat environment is used to generate both blue and red entities. The constructive wingman is generated here and is configured to follow the EBS. Additionally, sometimes during highly dynamic manoeuvres the constructive wingman can 'lose' the virtual F-35, in which case the operator resets its position.

Link-16 bridge – Software application which translates simulated tactical data messages to a message format which is understood by the Link-16 terminal, and vice versa. Secondly, it extracts certain information (e.g. Precise Position Location and Identification (PPLI) info) from tactical data link messages regarding live entities (e.g., radar tracks or PPLIs) and imports this into the simulation protocol of the synthetic environment (e.g., DIS) to get a representation of the live entities in the synthetic world.

Radio Bridge - An application which translates the digital voice communication to an analogue signal that can be transmitted via UHF/VHF. Specifically, this is an ASTI Radio Bridge[2].

Training benefits

During this LVC experiment it is evaluated to what extent LVC over Link-16 provides training benefits for the live pilots as well as the pilot in the simulator. Questionnaires are used to collect the opinion of the pilots on their training experience in relation to the synthetic elements in the exercise sorties. Interviews are used to gain more in depth insight. Both the pilots of the live and virtual aircraft are interviewed. The results of this evaluation show that an LVC environment using Link-16 provides training benefits in the planning and execution phase regardless of the limitations that a tactical data link imposes on the interaction between the live and virtual entities. The main benefit is believed to be in the increased complexity of a scenario as a result of the extra number of participants and additional roles like a protected entity or high value asset that can be added. Based on these results it can be argued that LVC over Link-16 can be a viable option to enhance day-to-day training. More details about this research experiment can be found in Petermeijer et al. (2024).

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[2] ASTI Voisus Communcations and Radio Bridge. URL: https://www.asti-usa.com/voisus/

LVC ARCHITECTURE DESIGN

The whole task use case and the practical implementation of an LVC setup at the Frisian Flag exercise are a basis for an architecture design study for an LVC environment which can be used by the RNLAF. The design study focuses on providing a solution architecture (i.e., the building blocks and patterns) to facilitate an integrated LVC environment. The design of a solution architecture requires a number of assumptions and preconditions to be able to choose and design specific solutions. Towards that end, a training scenario and training location are chosen as a basis for the design. The training scenario is the whole task use case in which various assets are deployed against a multitude of enemy threats. The methodology consists of the following parts:

1. Description of the current architectures - the study has identified several LVC architectures that have been used in previous studies and demonstrators, to indicate the current state and level of integration within the RNLAF.
2. Definition of use case scenario – a use case scenario has been selected that represents the desired training outcomes and operational contexts for the LVC environment. This use case scenario will serve as the foundation for identifying the required interactions between L, V, and C entities.
3. Identification of required interactions – based on the use case scenario, the required interactions between L, V, and C entities have been identified and the information to be exchanged between the entities for an effective training environment have been determined. These interactions and information requirements form the basis for the next step to determine the data requirements in the architecture.
4. Determination of data exchange requirement – the required interactions is then used to determine the data exchange requirements for the LVC environment. The use of a dedicated training data link is explored to enable more efficient and effective data exchange between L, V, and C entities. Specifically the frequency of exchange and the latency requirements required to facilitate effective training is investigated, as well as potential data formats and standards and protocols.
5. Design of high-level technical architecture – based on the data exchange requirements, a high-level technical architecture of the future LVC environment is created. This provides a blueprint for the overall system design, including the relationships between the different components, the data flows, and the technical requirements.

The architecture is used to investigate three topics specifically, namely:

- Link-16 as a data carrier
  This theme investigates the use of Link-16 as a data carrier for the LVC environment. This involves assessing the capabilities and limitations of Link-16, as well as identifying potential modifications or enhancements required to support the data exchange requirements.
- P5 training pods for dedicated data exchange
  This theme takes P5 training pods as a basis for researching the use of dedicated training data links for facilitating data exchange between live and synthetic entities. This involves evaluating the potential benefits and limitations of P5 training pods, as well as identifying potential integration challenges and requirements for a dedicated training data link.
- LVC requirements concerning operation and organization
  This theme focuses on the operational and organizational aspects of the LVC training environment. This involves identifying the requirements for training scenario development, exercise planning, and execution, as well as the organizational structures and processes required to support the LVC environment.

A FUTURE INTEGRATED LVC ENVIRONMENT

The FF'23 exercise showcases that LVC over Link-16 adds benefits in terms of training value despite the limitations the use of tactical data link impose. To fully realize the potential of LVC technology, a future training environment should be designed with three key principles in mind: modularity, scalability, and mobile infrastructure.

- Modularity
  Day-to-day training remains the foundation of fighter training, but with the evolving global landscape, joint and combined exercises are becoming increasingly vital. To meet this growing need, an LVC environment

must be capable of facilitating both small-scale and large-scale exercises. This demands a modular architecture that allows entities - whether virtual, live, or constructive - to be easily added, and in case of constructive elements be easily controlled, programmable with specific behaviour models. Furthermore, data streams must adhere to standards, enabling the seamless integration of gateways and bridges, and ensuring that the LVC environment can adapt to diverse training scenarios and scales. However, integrating live fighters into this environment may prove challenging, particularly when it comes to accepting training data from a dedicated training data link. P5 systems could serve as a stepping stone for these developments, but it is essential that these solutions are not created on a proprietary basis. Instead, standards for training data must be established, ensuring platform agnosticism and allowing for the free flow of data between different systems. Such a standard should not just focus on the facilitating the fighter community but adopt a multidomain perspective.

- Scalability
  In line with the previous paragraph, an LVC environment must be scalable to accommodate a wide range of training exercises, from small day-to-day training sessions to large international exercises. To achieve this, the LVC architecture should be designed to be flexible in terms of numbers, allowing it to easily scale up or down as needed. This places specific requirements on the hardware, which must be capable of handling varying workloads. A service-based architecture for generating constructives could be a viable solution, as it can be scaled up when necessary. Similarly, meeting scalability requirements for live and virtual entities also requires additional hardware, including data link terminals and simulators. Furthermore, any future training data link standards should be defined with scalability in mind. To ensure seamless communication, message services should be implemented, as traditional broadcasting protocols like DIS will likely encounter bandwidth issues in large exercises, compromising the effectiveness of the training environment

- Mobile Infrastructure
  Training in an international context demands a mobile infrastructure that can be easily transported to exercises abroad. This necessitates a flexible and portable architecture, where servers are placed in mobile racks within containers, similar to the Link-16 terminals currently in use. Additionally, simulators should be designed to be movable, allowing them to be quickly deployed and integrated into the training environment. However, this mobility raises critical security concerns, as both cyber and physical security protocols may be compromised. The security level of simulators must be carefully considered, as the risk of unauthorized access or data breaches could have serious consequences. As such, stringent security measures must be implemented to protect the integrity of the training environment and ensure the confidentiality of sensitive information.

While LVC over Link-16 partially meets these requirements, it falls short of providing a fully satisfactory solution. To meet all three principles to a satisfactory level, a dedicated training data link would be needed. Such a link would provide a secure, high-bandwidth, and low-latency connection, enabling the seamless integration of live, virtual, and constructive elements. By investing in a dedicated training data link, the fighter community can unlock the full potential of LVC technology, enhancing training effectiveness, and preparing for the challenges of modern airpower.

DEVELOPMENTS AND NEXT STEPS IN THE NETHERLANDS

The successful and well received experiment at FF’23 opens up several opportunities for next steps of this work. The major theme is to develop the concept of LVC integration for high-end complex training to day-to-day training. This breaks down into three lines of work.

The first effort is maturing the employed technology and the concept of operation for LVC training. Although leveraging existing networks and components, the setup at FF’23 was a one-off creation. For repeated operational usage the technology needs to be made more robust and integrated into existing networks. This means integration with standing data link networks and voice communication systems, instead of using custom solutions. Encountered issues such as limited radio coverage are resolved by these efforts. Increasing the usability of software systems and improved automation of the technology should reduce the required manpower to operate the capability.

Second, to bring the concept to day-to-day training a capable permanent operational centre is needed. Training sorties are typically supported from a so called War Room, where the training leader, red force commander, range training officer and such are performing their roles. The War Room would bring together all functionality of a 5th generation live training environment, with control over components such as adversary air, threat emitters and scenario control. The integration of LVC concepts in the training is also to be incorporated in the War Room, making the live and synthetic environments a seamless experience for trainees and supporting personnel. Typical functions available in a War Room include a Common Operational Picture (COP), communication networks to coordinate blue and red force players, systems to operate training range instruments and control of constructive elements.

Lastly, the addition of virtual entities into the scenario completes the LVC capability. A number of simulators can be placed on-site with the War Room and allow virtual players to participate in training scenarios. While in FF'23 a single virtual player is combined with a constructive wingman, this number could be scaled up as need for virtual players grows. One or several virtual 4-ships are logical numbers to complement. Mixing live and virtual ships in a single 4-ship would be a an additional complexity, but a full virtual 4-ship could perform meaningful roles in larger scale scenarios. Virtual red air players are also among the possibilities, perhaps piloted by former pilots or reserves to allow active duty personnel to get as much high-end blue air training as possible.

Aside of these developments Subject Matter Experts (SMEs), such as pilots, can identify the training value associated with performing a task either live or virtually. This information is crucial for effective planning of training and exercises. However, incorporating this expertise into the planning process can be a complex and time-consuming task, especially when resources are subject to change (e.g., a reduction in available aircraft). A key challenge is determining which elements to revert to virtual training first, based on their training value. Currently, there is a lack of understanding on how to capture and utilize this knowledge to develop supportive tooling. As day-to-day training scenarios become increasingly complex due to the integration of LVC elements, the need for planning tools becomes more pressing to avoid a planning nightmare.

Finally, operating Live, Virtual, and Constructive (LVC) training environments, particularly in large exercises, raises several safety-related questions. For instance, how can confusion between live and synthetic entities be prevented? Should virtual entities adhere to the same restrictions and training rules as live entities? Is it safe for a live aircraft to fly through the altitude box of a synthetic entity? While SMEs can make informed judgments based on their experience, there is a lack of solid, empirical evidence and best practices in safely operating LVC environments, highlighting the need for further research and experience.

KEY FINDINGS AND LESSONS LEARNED

The research program provides NLR and the RNLAF with a number of valuable insights. The key findings and lessons learnt are:

- **LVC over Link-16 works**
  The experiment successfully demonstrated the technical feasibility of LVC over Link-16, and live pilots acknowledged the added training value provided by the virtual as well as constructive entities.
- **Virtual players also benefit from LVC**
  The experiment demonstrated that LVC offers also training benefits for the virtual players, particularly in terms of training communication between players and planning and coordination of the mission. By participating in LVC scenarios, virtual players can improve their skills and gain experience in a more realistic and dynamic environment.
- **Leveraging existing infrastructure**
  The experiment showed that UHF and Link-16, existing and operational infrastructures, can be utilized to support LVC training. Demonstrating that LVC over Link-16 is an viable short-term solution to complement typical day-to-day training exercises, without the need for major investments in development in a novel infrastructure.
- **Technical support costs**
  Nonetheless, the first-time setup of LVC over Link-16 required significant technical support to set up. The required technical support should be able to decrease with further development and refinement of the technology.
- **Virtual players should be fully integrated into the mission cycle**

The experiment revealed that virtual players were often relegated to a side-role in the planning phase and not deployed as the live aircraft would be. To maximize the benefits of LVC, simulator pilots should be fully integrated into the mission cycle, participating in planning and execution alongside live players.

The overall conclusion is that the FF'23 experiment demonstrated the potential of LVC over Link-16 to enhance day-to-day training, and identified several key lessons learned that can inform future LVC development and implementation. By building on these findings, the RNLAF can continue to develop and refine its LVC capabilities, ultimately enhancing the effectiveness and efficiency of its training programs.

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