# Integrating a virtual simulator in a large-scale live exercise – lessons learned regarding training and operations aspects

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**Technical Paper**— LVC training for fighter pilots has been argued to reduce training cost, enrich training scenarios and to be flexible and scalable. An LVC environment with a high level of interoperability requires a dedicated datalink 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 an highly interoperable LVC environment will become prevalent in the coming years. Fortunately, a highly interoperable 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 datalinks 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. The goal of this research is to investigate how day-to-day training can be facilitated without major changes to the training organisation and investment and to what extend such a set-up can offer in terms of training benefits. In October 2023 a synthetic environment – consisting of a virtual fighter and several constructive entities – was integrated into a large-scale international live flying exercise. The synthetic and live entities were able to exchange data through an operational Link-16 datalink. The virtual simulator joined the training scenario as a two-ship and supported the live players in their Offensive and Defensive Counter Air missions. After the training exercises the perceived added training value, for the live pilots as well as the pilot in the simulator, was evaluated through questionnaires and interviews. A detailed analysis of the results and a synthesis of the lessons learned is currently being performed. Preliminary results show that the virtual simulator and constructive entities add to the perceived training value of the live pilots. Moreover, the pilots of the virtual simulator also experienced training value in the simulator, albeit of a reduced magnitude. The preparation and operation of the LVC environment required too much technical support to offer a realistic option for day-to-day training in the current setup, but these are foreseen to be surmountable without excessive effort. Finally, the paper describes the design of a LVC environment in more detail, the training value such a setup is foreseen to offer, and the operational requirements in order to be effectively integrated in day-to-day training.

## 1 Introduction

In an LVC training live (L), virtual (V), and constructive (C) entities are combined in a single training environment where these entities can interoperate with each other. LVC training has been argued to reduce training cost, enrich training scenarios and to be flexible and scalable. Modern fighters are typically equipped with embedded training (ET) modules, which allows live pilots to train in flight groups against constructive adversaries. However, for an LVC-environment that facilitated a high level of interoperability between all three types of entities (L,V, and C) a dedicated datalink to exchange training data with a high throughput and low latency is required. Moreover, such a training datalink should be allowed to input data in the OFP of the aircraft, which is currently not possible. Alternatively, embedded training (ET) modules provide an option to train against constructives but these are closed systems with no external data exchange. That is, typically ET data is only shared between fighters within a flight group and is not able to exchange data via other means (e.g., no data can be shared from ET-module to a Link-16). Research and development regarding the standardization of such links and technology is ongoing, but it is unlikely a highly interoperable LVC environment can be implemented in the coming years.

Fortunately, a fully integrated LVC environment is not required to enhance the relatively simple scenarios for day-to-day training. Using existing technologies and operational tactical datalinks 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.

Therefore, goal of this research is twofold: 1) to investigate the technological requirements, in terms of architecture, hardware and software, to facilitate LVC-training using an operational tactical datalink; and 2) to

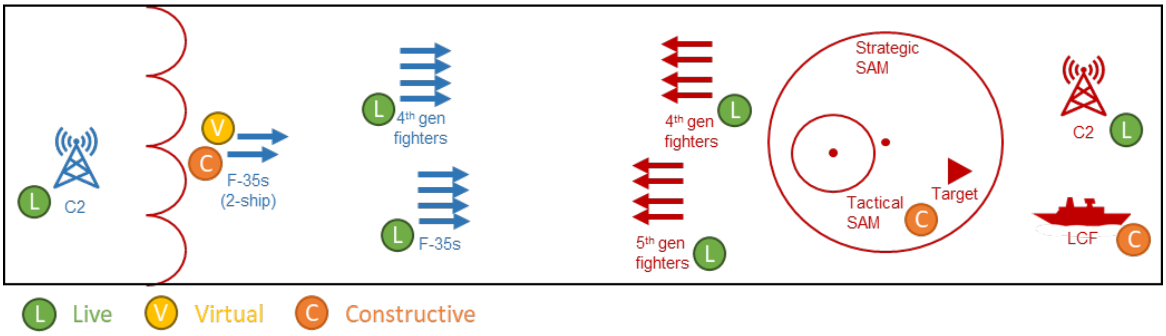


**Fig. 1.** The basic training scenario on which the research is based. The green circles (L) indicate the live entities, the yellow (V) indicate virtual entities, and the orange (C) indicate constructive entities.

investigate what trainings benefits such a set-up would offer the live pilot and pilot in the simulator.

## 2 The large-scale training exercise

The research was conducted during the live large-scale exercise Frisian Flag 2023 (FF`23), where the Royal Netherland Aerospace Centre (NLR) in collaboration with TNO supported the Netherlands Air Force 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). The LVC environment was used in both OCA and DCA missions, but for the sake of simplicity a generic OCA scenario is described below and shown in Figure 1.

### 2.1 Training scenario

In the generic OCA scenario blue live fighters – typically multiple 4th and 5th generation 4-ships – will engage adversary (red) fighters – multiple 4th and 5th generation 4-ships – and encounter integrated air missile defence (IAMD). The mission goal in the example is to take out a ground target. The live 5th gen fighters will engage the adversaries, while the virtual aircraft will take on the role of a bomber (i.e., a fighter with a A/G focused weapon load). Live fighters will 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. After the enemy threat has been taken out the 5th gen fighters return to suppress the enemy air defences.

The scenario is predominantly aimed at live training, meaning that the fighters and fighter controllers (C2) are live players. The bomber is a virtual entity (i.e., simulator with live pilot) that is accompanied by a constructive wingman programmed to follow the virtual F-35. On the red side the target and IAMD are constructive entities, as well as a LCF which was used to the provide the position of the virtual and constructive blue entities to the live fighters (see section 3 for more detail).

### 2.2 Training roles and execution

#### *2.2.1 Live fighters and fighter controllers:*

*F-35 and 4th generation blue fighters*: The training scenario is primarily aimed to deliver training value to the live pilots, and as training needs to be as realistic as possible (i.e., train as you fight) these fighters were flying live. The 4th generation fighters included of F-16s, Eurofighters, and F-18s.

*F-35's and 4th generation red air*: FF'23 is a live exercise so the red air entities that will be engaged are also live aircraft.

*Command & Control*: Fighter controllers are an integral part of these exercises, hence they will be live as well.

#### *2.2.2. Synthetic two-ship*

*A virtual F-35*: The main goal of the synthetic players is to increase complexity of the scenario. Therefore, the training scenario is less focussed 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 OCA F-35 pilots by adding extra coordination and communication. Therefore, the bomber is assigned to be virtual.

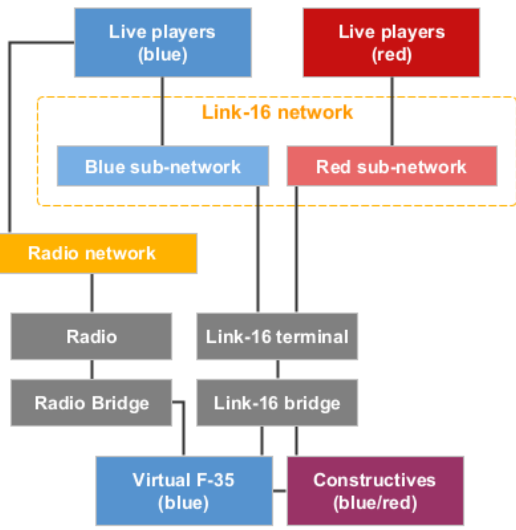


Fig. 2. The general LVC architecture that was used during the FF`23 exercise.

**Table 1.** Data exchange between live and synthetic entities over Link-16.

| Level | Data | Interaction |
|---|---|---|
| 1 | – J2.2 PPLI<br>– Bidirectional voice communication<br>– EAG file/shotlog | – Blue live and virtual entities are able to see each other's PPLI's on their PVI.<br>– Blue live and virtual entities can verbally communicate.<br>– Virtual player can participate in the mass debrief. |
| 2 | – Level 1 and<br>– J12.6 Target Sorting/J3.2 Air Track/J3.5 Ground Track (live to virtual)<br>– Representative Mission Data File | – The virtual player can see the position, speed, and direction of red air entities, and position of ground entities.<br>– Representative MDF increases the training value for the pilot in the simulator. |
| 3 | – Level 2 and<br>– J12.6 Target Sorting (virtual to live)<br>– Representative virtual weapons | – Allows the virtual pilot to interact with the live entities more realistically, as it allows the virtual entity to pass sensor data.<br>– Realistic weapon models increase the training value for the pilot in the simulator. |

#### *2.2.3.* Constructive entities

*A constructive F-35*: This is the wingman of the virtual F-35. A single F-35 would be unrealistic, so a constructive F-35 will be created to follow the virtual one. The constructive F-35 did not have a weapon load out and could not engage adversaries. Accordingly, the simulator pilot had access to double the amount of ammunition. That is, they were allowed to reset their weapon load once during a scenario, so that the 2-ship had identical fire power to an actual 2-ship.

*LCF*: a red LCF is a constructive entity, as its main purpose is to provide a PPLI's of the virtual and constructive entities for the live red platforms.

SAM-sites: No live radar emitters were available at FF'23, so the behaviour of SAM-sites (i.e., radar locks, tracks, and engages) are communicated over the UHF/VHF radio.

*Target*: Typically the target is a location on the ground which needs to be engage with a A/G weapon. However, no live fire is used during FF'23 so these targets is considered a constructive.

*SAM-sites:* The location of the red air SAM-sites are known before the scenario started. Typically, in a live exercise the behaviour of enemy SAM-site is called out on the radio. Constructive copies where generated in the synthetic threat environment and an operator would manually control the SAM-sites based on the radio calls, which would trigger radar warnings in the simulator.

## 3 LVC Architecture

This section specifies the architecture used to create the LVC training environment. It describes the overall concept architecture, the elements and the interaction that were possible between the live and synthetic entities.

### 3.1 Architecture elements

The architecture consists of the following elements:

*Live players* – Red and blue aircraft and C2-cells connected 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 F-35* – An Effects Based Simulator (EBS) was used to simulate the F-35. The EBS utilized Distributed Interactive Simulation (DIS) [1] standard to interoperate with the other synthetic[a] elements in the architecture. The EBS used DIS voice messages that were sent to the radio bridge for live voice communication with the live blue players. The EBS used DIS SISO-J messages to communicate with the tactical datalink network and sent these SISO-J messages to the Link-16 Bridge.

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

*Link-16 bridge* – Software application which translates simulated tactical data messages (e.g., SISO-J or JREAP) to a message format which is understood by the Link-16 terminal, and vice versa. Secondly, it should extract certain information (e.g. PPLI info) from tactical datalink messages regarding live entities (e.g., radar tracks or PPLIs) and import 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 translate the digital voice communication to an analogue signal that can be transmitted via UHF/VHF. Specifically, this was an ASTI Radio Bridge [2].

### 3.2 Data and interaction

Link-16 is an operational tactical datalink, 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

[a] This study regards Synthetic entities to be both the virtual and constructive entities.

facilitate a high level of interoperability. Table 2 shows the Link-16 messages that could be exchanged between the live and virtual entities and subsequently the interaction that those messages would allow.

# 4 Training value

## 4.1 Method

The second aim of this study was to evaluate to what extend LVC over Link-16 will provide training benefits for the live pilots as well as the pilot in the simulator. Specifically, three research questions were investigated:

1) How is the training value related to the LVC setup perceived by the airborne pilots?
2) How is the training value of the exercise perceived by the pilot of the virtual entity?
3) How can an LVC environment be applied in pilot training?

Questionnaires to collect the opinion of the airborne pilots on their training experience in relation to the virtual entity were distributed after each sortie. The topics in the questionnaire were the integration of the virtual entity, collaboration with the virtual entity and added training value of the presence of the virtual entity. Besides that, the pilots were asked what their call sign and role in the exercise was.

Moreover, interviews were used to gain more in depth insight into the research questions. Both the pilots of the live and virtual aircraft were interviewed.

. Multiple pilots operated the simulator (virtual) over the course of the exercise. These interviews followed a semi-structured format, covering largely the same topics as those addressed in the questionnaire. Additionally, the technical implementation of the simulator was a topic. Pilots were asked about the realism of various technical systems, such as radar and Link-16. Prior to the exercise, the availability and functionality of these systems in the simulator were made known to them, including any notable absences and limitations, in order to prevent surprises during the training scenario.

Semi-structured interviews were also user for the pilots of the live aircraft. A precondition to participate in the interviews was that the pilot had a leadership role (e.g. flight lead, section lead or mission commander) during the training. The goal of the interview was to gain in depth insights regarding the same topics as the previously mentioned interview. Simulator integration was also a topic, but from the perspective of the airborne pilot.

## 4.2 Results

The questionnaire resulted in 86 responses during the two-week exercise. Sixty responses were flying blue air and 24 were flying red air when attending the mass debrief. This section does not provide an extensive overview of the results but will highlight several important results from the questionnaires as well as the interviews.

The most prominent result is that, when asked, participants unanimously indicated that the virtual entity added training value to the exercise. Pilots noted that the inclusion of each extra asset contributes to the complexity of both planning and execution of the gameplan. The introduced assets, comprising one virtual and one constructive aircraft, were regarded as realistic additions to the exercise. The airborne pilots benefited from this addition as it allowed for the realistic execution of a task that would have been left out if these entities were not present. The absence of these assets might have resulted in a less complex scenario, thereby diminishing the training value.

For the simulator pilot the added training value was less straightforward, as the fidelity of the EBS is not to the level that all tasks can be executed realistically. Moreover, the EBS was not able to communicate over MADL with other blue F-35's resulting, for example, in a slight deviation in the targeting process. Nonetheless, in the interviews simulator pilots indicated that they did feel part of the training exercise.

Due to technical reasons it took several days for the virtual entity to be stably visible on the red side Link-16 subnet. Part of the issue was that the assigned timeslots of the Link-16 network were not properly configured. In general a relatively large support staff was required to operate and monitor the LVC set-up. As the LVC set up was a proof-of-concept this is not suprising, however support staff would need to be reduced if LVC over Link-16 was ever implemented in day-to-day training.

Reports of an instable Link-16 were predominantly noted in the first days of the exercise and decreased over time. An instable Link-16 is likely to diminish the experience of interoperability between the live and virtual entities. However the subjective interoperability seemed to increase increased across the duration of the exercise and ultimately the virtual entity was regarded as an integral part of the training scenario, as was evident by the shot calls from the live aircraft to the virtual entity.

Finally, trust in the technology played a significant role in the acceptance of the virtual entity as part of the training scenario. It was observed that exposure to the technology increased trust in the live pilots over the duration of the exercise. This probably contributed to increasing perception that the virtual entity was an integral part of the training scenario for both the live and the simulator pilots. This observation is substantiated by the fact that the virtual entity was assigned increasingly more tasks over the course of the exercise. At first, the virtual entity was assigned isolated tasks which would not disrupt the training scenario when unaccomplished, but over time the virtual entity was assigned tasks that were more vital for the completion of the training exercise as a whole.

# 5 Conclusions and recommendations

This study has shown that an LVC environment using Link-16 provides training benefits, regardless of the limitations that a tactical datalink 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. Based on these results it can be argued that LVC over Link-16 can be a viable option to enhance day-to-day training.

Nonetheless, this proof-of-concept also showed that there are several technical issues to be solved for this set-up to be a viable option for day-to-day training. A stable Link-16 connection is an important requirement for day-to-day training. Moreover, the support staff to prepare, design, ensure a stable and continuous operation for and during the exercise numbered several technicians. This would be unacceptable for a day-to-day training facility, which needs to be plug-and-play. Yet, the technical experts believe that these issues can be overcome and that technical support could be reduced to the extend of a typical simulator facility.

Developments of simulation datalinks to facilitate LVC environments with a high level of interoperability are underway, but their operationalization into national air forces is believed not to be happening in to coming decade, we believe LVC over Link-16 provides a solution for the intermediate time period.

## References

[1] IEEE Standard for Distributed Interactive Simulation – Application Protocols. IEEE – Std. 1278.1-2012.

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

## Author/Speaker Biographies

Bastiaan Petermeijer is a R&D Engineer at the Royal Netherlands Aerospace Centre since 2020. He received his PhD degree from the Technical University of Munich in 2017 in the field of human-machine interaction. His current research focuses on the application of simulation technology for training purposes. His interests focus trade-off between the technical possibilities and the training value these offer.

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