An Embedded Training Multi-Ship Demonstrator

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ABSTRACT

Embedded Training provides training capabilities built into or added onto operational systems, subsystems or equipment to enhance and maintain the skill proficiency of personnel. The Joint Strike Fighter program requires an Embedded Training (ET) solution capable of multi-ship interaction, local and distributed weapons simulation, data link, data collection and off-board debriefing.

Dutch Space and NLR in cooperation with the Royal Netherlands Air Force demonstrated Embedded Training on an F-16 MLU in the E-CATS Demonstrator event April 2004. This event provided aircrew with the opportunity to fly the E-CATS demonstrator and helped shape the ET requirements for the F-35.

E-CATS was a very successful demonstration of single ship ET, however to “train as we fight” requires a multi-ship ET solution. Dutch Space and NLR developed a demonstrator to provide an understanding of the functional ET multi-ship concept from an operator perspective. It allows a pilot to interact with the system and understand what an ET multi-ship capability can provide to him. This demonstrator is therefore ideally suited to provide the operational user with the data and experience necessary to refine ET functional requirements.

The demonstration of multi-ship ET capability takes place in a simulated environment. It is based on NLR’s multi-ship research facility F4S (Fighter Four-Ship) consisting of four mobile fighter aircraft simulators. The single ship E-CATS demonstrator capability is integrated with enhanced extensions to enable the multi-ship ET functionality to be demonstrated to the users. The users are able to fly an ET mission in a multi-ship configuration and compare that to a single ship solution allowing unique multi-ship requirements to be identified.

ABOUT THE AUTHOR

Arjan Lemmers graduated from the Delft University of Technology, where he studied Aeronautical Engineering. Afterwards he joined the Royal Netherlands Navy for 2 years as a lecturer and research fellow for control theory. Since 1998 Arjan is working for the National Aerospace Laboratory NLR in the field of flight simulation, distributed simulation and training technology. Currently he is in the Training & Simulation department as senior R&D manager modeling & simulation.

His work has principally involved the development, evaluation and management of new training, simulation and supporting techniques for simulator training with a focus on distributed and embedded training. He was as NLR program manager involved in the EUCLID RTP11.13 study “Realising the potential of networked simulations in Europe”, member of the technical task team of the NATO SAS-34 study “Mission Training through Distributed Simulation”, also known as Exercise First WAVE, and the NLR representative in the consortium for upgrade of the NATO AWACS Mission Simulator in Geilenkirchen. Since 1999 he has been involved in several research and demonstration projects regarding Embedded Training. He coordinates the Embedded Training activities in the Training and Simulation department.

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INTRODUCTION

Since the mid 90s the National Aerospace Laboratory NLR and Dutch Space have been working on developing the concept of Embedded Training (ET) for fighter aircraft. Several projects have been performed successfully from an initial concept study to an implementation and demonstration of a prototype Embedded Training System in a Royal Netherlands Air Force (RNLAF) F-16. Considerable knowledge and practical experience in developing, integrating, testing and demonstrating ET has been gained in the past 10 years.

The single ship demonstrations provided a major step forward, but to "train as we fight" requires the ability to train as a team with multiple aircraft. In 2005 NLR and Dutch Space therefore started investigating multi-ship ET solutions. In January 2007, the Joint Strike Fighter (JSF) Program Office awarded NLR and Dutch Space with a contract to provide a simulator based demonstration of Multi-Ship ET. The objective of the demonstration was to provide an understanding of the functional ET multi-ship concept from an operator perspective. This would allow a pilot to interact with the system and understand what an ET multi-ship capability can provide to him. This demonstrator is therefore ideally suited to provide the military user with the data and experience necessary to refine their ET functional requirements.

This paper describes the Multi-Ship ET demonstrator and its functionality. It starts with an explanation of the Embedded Training concept. This is followed by an overview of the past experiences of NLR and Dutch Space on Embedded Training. Then it describes the current demonstrator project and the objectives of the demonstrator. The technical architecture of the demonstrator will be explained. The paper finishes with recommendations for the following steps to be undertaken to integrate Embedded Training in the modern fighters and their training curriculum.

WHAT IS EMBEDDED TRAINING?

Embedded Training provides training capabilities built into or added onto operational systems, subsystems or equipment to enhance and maintain the skill proficiency of personnel. ET enables the operator to use the weapon system in situations where it was designed for, while this situation is not available in every day life, while using the real system.

ET is not completely new. Existing examples of ET can already be found in some operational systems like the Patriot Air Defense Missile system and on naval warships. In fighter aircraft there are some systems making use of simulation technology like the 'master arm switch' to simulate missile fly-outs. ET also traces back to the onset of digitization on-board and the growth of Autonomous Air Combat Maneuvering Instrumentation (AACMI) where the addition of data links, GPS and a processing capability allowed aircraft to train together and fire simulated weapons. ET goes a step further with generating a synthetic virtual world on-board the real fighter aircraft. ET brings the advantages of live flying and mission simulation together.

The ET System (ETS) will be an integral part of the overall training system and can be used on a daily basis at the operational and training squadrons. The ETS will take its own place in the range of training system devices. It does not supersede one of the current training systems. It can be used in specific lessons in the syllabus at the schoolhouse with tailored scenarios. At the operational squadrons it can be used almost daily in flights either as single ship or in conjunction with other aircraft and AACMI.

The ETS for fighter aircraft injects virtual air and SAM threats into aircraft systems, allowing fighter pilots more intensive training against a virtual force, or virtually augmented real red and blue force, with a debrief playback capability on-ground.

Embedded Training gives a range of benefits:

- Enlarge training range
- SAM training anywhere, anytime
- Secure low-cost readily available Electronic Warfare (EW) training
- Increase of effectiveness and higher quality of flight hours:
  - Reduction flying as red at least 10%
  - Missile fly-outs
  - Very realistic emissions of ground threats
  - More variations in tactical environment
  - Several scenarios in 1 sortie

Analysis has shown 30% increase of training effectiveness at the same cost when using ET (estimates concerning RNLAF for F-16 Continuation Training) (Stokkel and Wegkamp, 2006).

OVERVIEW OF ET HISTORY IN THE NETHERLANDS

The Embedded Training concept for fighter aircraft in the Netherlands took off in 1997 with an international study on general aspects of ET for fighter pilots. In 2000 it was followed by two parallel studies and demonstrators of two different applications of ET:

- Technology and concept demonstrator in close cooperation with Lockheed using the F-16 MLU simulator at NLR
- Follow-up international study, resulting in a real life demonstration in a yet training aircraft (without radar)

In mid 2003 a project with the goal to integrate single-ship ET functionality in an F-16 MLU (in 8 months!) started. NLR and Dutch Space in cooperation with the Royal Netherlands Air Force demonstrated Embedded Training on an F-16 MLU in the E-CATS Demonstrator event April 2004 (Krijn and Wedzinga, 2004). This event provided aircrew with the opportunity to fly the E-CATS demonstrator (Figure 1) and helped shape the ET requirements for the F-35. In Figure 2 an example is given of the presentation of synthetic players in an F-16 cockpit.

Figure 1. E-CATS demonstrator in RNLAF F-16

A follow-on study for the RNLAF was completed in November 2005. In this study NLR and Dutch Space investigated the feasibility of multi-ship ET for existing F-16 fighter aircraft. The main goals of this study were to investigate:

- if ETS can technically be realized in existing F-16 aircraft
- if it is economically worthwhile to invest in such capability.

The project has demonstrated that integration of an ETS on F-16 fighters is technically feasible. It also showed that an ETS can provide a significant increase in training effectiveness which can be obtained with a relative fast return on investment (Stokkel and Wegkamp, 2006). Most of the benefits are achieved in the daily Continuation Training programs.

Figure 2. Synthetic players presented in F-16 cockpit

In 2006 the JSF Joint Program Office requested NLR to perform a demonstration on multi-ship Embedded Training at the Lockheed Martin facility in Fort Worth. The demonstration took place during the last week in June 2007. The purpose of this demo was two fold:

- Increase the awareness of US force for the capabilities of Embedded Training
- Demonstrate Multi-ship Embedded Training

This Multi-ship demonstration used two cockpits of NLR's Fighter Four Ship (F4S) Simulator System. The Embedded Training software is based on the in previous projects developed ET software elaborated with some new multi-ship ET functionality.

ET SYSTEM CONCEPT

In Figure 3 the architecture of an ET system on-board a fighter aircraft is presented. This ETS consists of several blocks, each with its own specific role. A short high level description of the main building blocks will follow now.

The main functionality of the ET system is to inject virtual air and ground threats into the fighter aircraft systems and calculate the impact of these virtual players on the aircraft. Therefore the system has to simulate the systems that normally detect these threats, for example the Fire Control Radar (FCR) or the Radar Warning Receiver (RWR). This functionality is represented in the *Own-ship Simulation / Stimulation* block in Figure 3. Also the own-ship missile fly-outs, chaff dispensing and the damage to the own-ship by the virtual missiles are calculated in this block.

These simulated systems make use of a virtual world. This virtual world contains all virtual entities. The behavior of these entities needs to be simulated, so that they can respond realistically to the other entities in the scenario, either being real or virtual players. Therefore information about the ownship, this is the fighter itself, and the real world has to be presented, after processing into a suitable format, to the virtual world generator. This functionality is provided by the block *Virtual World Simulation*.

Outside this main functionality there are supporting functions needed. In the first place the operation of the ETS via pages on the Multi Function Displays (MFDs) and the management of the virtual world and the ET scenarios. The results of the scenario or errors in the ETS operation are displayed to the pilot. This all is covered by the *Simulation Management* block.

An other important issue is the safety of aircraft and pilot. Therefore a special *Safeguarding* function is available. Safeguarding will turn off the ETS system when an unsafe situation occurs. This can be the case when the fighter is flying out of its training area, is closing to a civil airliner or a system error occurs.

If the ETS is active and there are no safeguarding issues, the output of the simulated systems is put on the data buses of the aircraft. In this way the other avionics and weapon systems of the fighter aircraft can respond to the injected data as if it is coming from the real sensors. For example the Dynamic Launch Zone (DLZ) will be calculated, just as it would be for a real threat. The A/C Data arrow represents this injection into the data buses.

For debriefing and analysis requirements there is a *Data Logging* block. In this block the data from the ET training missions will be stored. This can be both the real and virtual world data. This data can be downloaded from the fighter at the ground and replayed in a debrief tool. Other possibilities are to use this data in automated performance assessment tools.

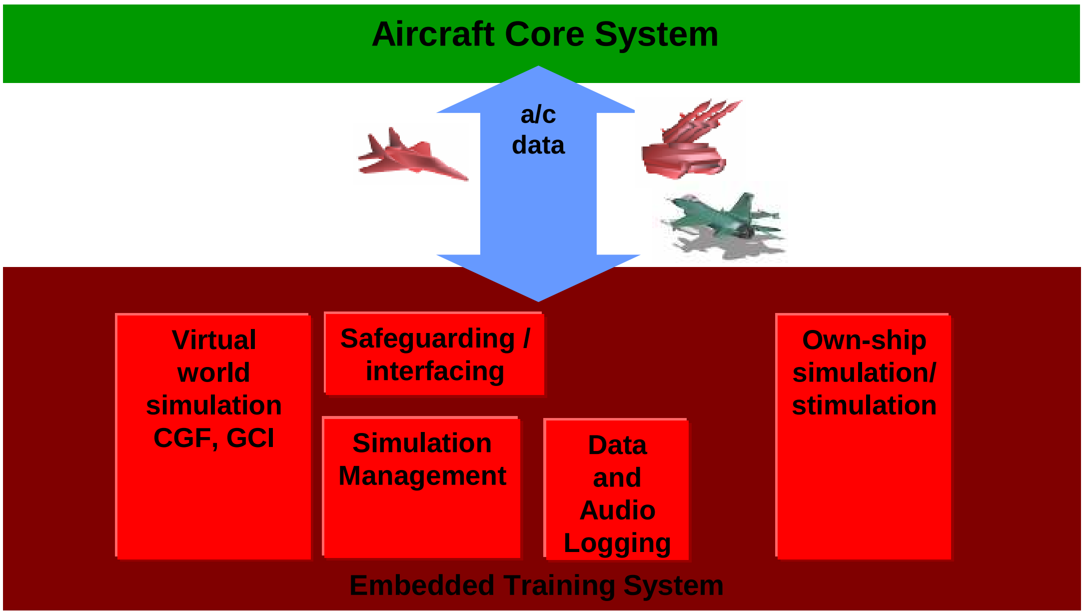

Figure 3. ETS concept

THE EMBEDDED TRAINING MULTISHIP DEMONSTRATOR PROJECT

The objective of the demonstration is to provide an understanding from a user perspective of the functional concept of multi-ship ET, including planning and debrief. It allows the user to interact with the system and understand what an ET multi-ship capability can provide to the user and thereby support refinement of the functional ET requirements. The focus here is on sharpening the ET multi ship requirements for:

- relevance of Simulation Data Link
- synergy between Autonomous Air Combat Manoeuvring Instrumentation (AACMI) System (Range Instrumentation) and ET functionality
- utilization aspects

The demonstration of multi-ship ET capability takes place in a simulated environment. It is based on NLR's multi-ship research facility F4S consisting of generic fighter aircraft simulators. The single ship E-CATS demonstrator capability is integrated with enhanced extensions to enable the multi-ship ET functionality to be demonstrated to the users. The users are able to fly an ET mission in a multi-ship configuration and compare to a single ship solution allowing unique multi-ship requirements to be identified.

Utilizing the portability of the research facility, the demonstration takes place in a 2-ship configuration at Lockheed Martin in Fort Worth, Texas, to allow additional JSF team members to assess the proposed multi-ship ET functionality.

THE DEMONSTRATOR SET-UP

In this paragraph the ET multi-ship demonstrator will be explained. First an overview is given of NLR's F4S research facility.

F4S overview

The F4S is a networked simulation facility that consists of four tube-framed mock-ups, each equipped with throttle and stick and a large high-resolution LCD touch-screen, see Figure 4. The touch-screen is used to simulate the cockpit, initially the F-16 cockpit as flown by the RNLAF. The large touch-screen however makes it relatively easy to simulate other cockpits (Keuning, 2007).

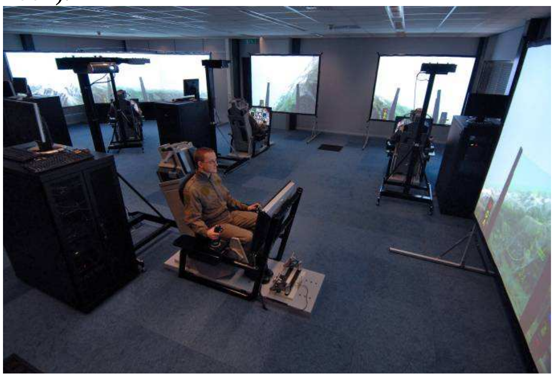

Figure 4. F4S research facility

The F4S is a human in the loop facility, where humans participate in experiments. Among the long standing capabilities of the NLR is the ability to monitor the participants during an experiment using several human factors measurement tools and as such collect objective information next to the feedback from the participants.

The F-16 simulation of each F4S ship is shared with that of the high-fidelity full-mission GFORCE simulator, only differences in external communication interfaces exist. Modern PC technology enables the use of these high fidelity models in a low cost facility like the F4S. The models of the F-16 vehicle simulation are maintained in-house at NLR since the inception of the facility. Work is continuously done to keep the models up-to-date with respect to the real F-16 configurations of the RNLAF. NLR has access to all the source code of the vehicle simulation, so the F4S is perfectly suited for injecting new concepts into an existing aircraft and researching the effects of this new concept.

Aside from the F-16 simulation models the F4S exists of software tools to generate a realistic operational environment for fighter missions. The high fidelity commercial Computer Generated Forces package S-Mission, formerly known as STRIVE, is present to generate threats. The commercial ASTI package is used for providing the audio communication between the pilots and between the F4S operator and the pilots. Supporting systems are available for mission planning, briefing and debriefing. In this way pilots can prepare their mission in the same way as they used to in their squadrons.

Figure 5 provides an overview of the F4S architecture.

ET multi-ship demonstrator set-up

Figure 5 illustrates how the ETS is integrated in the F4S. The ETS is incorporated in the F-16 simulation software block as if it is a real operational F-16 system. For the demonstration 2 cockpits of the F4S are used. A dedicated Ethernet line is used for simulation of the ET data exchange between the F-16s over the ET datalink.

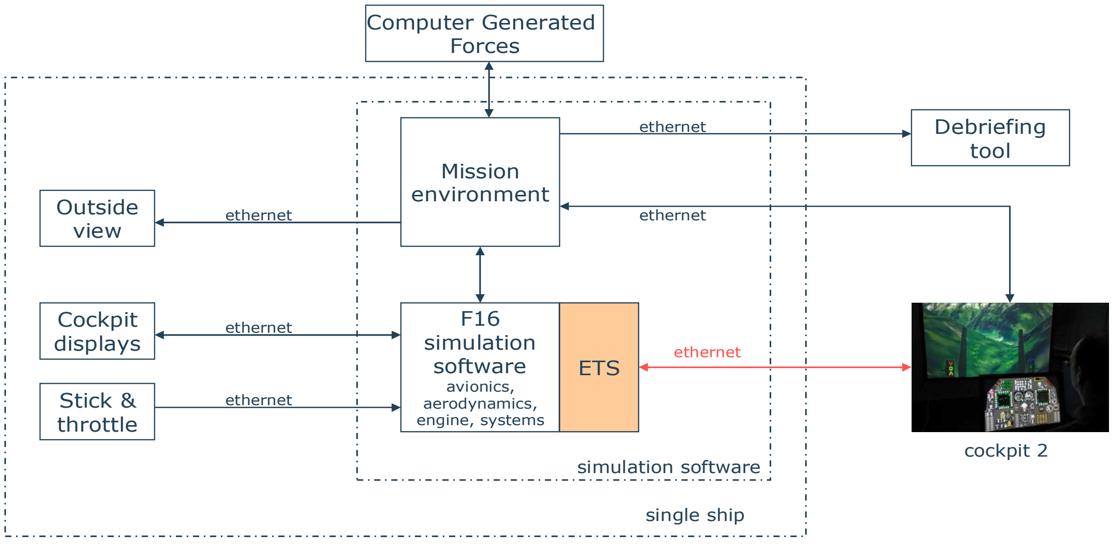

Figure 5. F4S architecture

Figure 6 zooms in to the implementation of ETS in the F-16 simulation software. An ET software module generates all the ET functionality. The kernel of this ET module is the Virtual Mission Environment. In this Virtual Mission Environment all data of the virtual world is gathered and from this block the communication to the other F-16 systems takes place over the data buses.

For generating the virtual entities a CGF block is present. This block simulates the air and ground threats for the ET scenarios. The data of these entities, e.g. entity state, emission data, is send to the Virtual Mission Environment module. From the Virtual Mission Environment the CGF block receives the data of the real world, so the virtual players can react to the real world entities.

The functionality of a number of avionics systems is simulated or stimulated during the ET missions. These are (sensor) systems that have interaction with the other entities. In Figure 6 is represented by the blocks 'Stimulated/simulated aircraft systems'. In these blocks the interactions of these systems with the virtual entities take place. The output of these systems is sent to the Virtual Mission Environment from where it is inserted in the data buses of the F-16. In this way the virtual world is mixed with the real world and can be presented on the cockpit displays and audio warning systems.

The Embedded Training Data Link (ETDL) is represented by a separate module in the ETS implementation. This block generates the data that must be shared with the ETS system on board the second F-16. This data exists of data about the virtual threats generated on board of the F-16 and data for management of the ET scenarios.

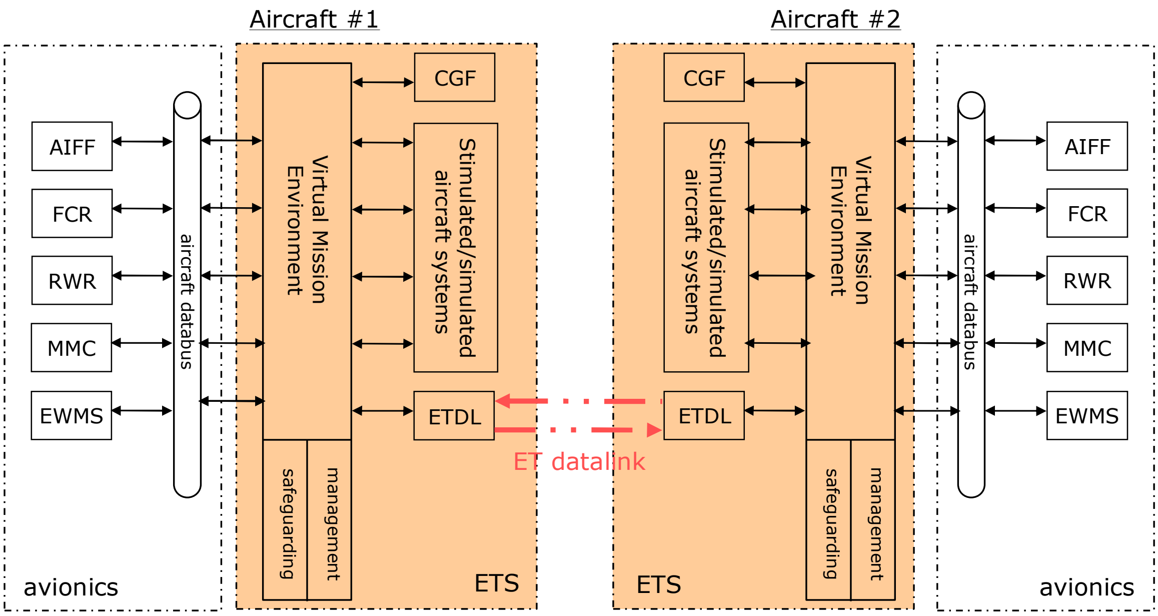

Figure 6. ET multi-ship implementation in F4S

Finally there are two blocks dedicated to a safe operation of the ETS, the 'safeguarding' and 'management' blocks. These blocks contain functionality like:

- start and stop ET scenario
- selection of scenario
- check if F-16 is in correct and safe position to start scenario
- check if the wingman is ready for the scenario
- outcome of the ET scenario
- and more.

Interaction with the pilot for these functions takes place through dedicated ETS pages on the MFD. In Figure 7 an example of an ETS page is presented.

Figure 7. Screenshot of ETS page on MFD

ET Multi-ship demonstration

The demonstration took place on June 26th and 27th 2007 at the Lockheed Martin premises in Fort Worth. The demonstration was flown by two RNLAF F-16 pilots (Figure 8). In the demonstration the ETS generates surface-to-air and air-to-air threats. It emulates the sensor systems of these threats (RADAR, RWR, IRSTS etc.). The threats are modeled using realistic system capabilities. Their weapon load consists of RF (Radio Frequency) and IR (Infra Red) guided missiles. The behavior of the CGF can be tailored or randomized on the basis of an “awareness level”. Also the shot doctrine and tactical usage of missiles can be tailored.

During the demonstration the operation of Multi-ship ET was demonstrated:

- Simulation Management & Scenario Selection
  - Control through ETS Control page on MFD
  - Scenarios are predefined and loaded on each a/c
  - Scenarios selected in each aircraft
  - Mode Selection, i.e. Single Ship / Multi ship Master / Multi ship Slave
  - Start / Stop Conditions
- Safe-Guarding
  - Conditions that will exit a running scenario or prevent start of a scenario for safety reasons e.g. short on fuel, leaving training area

Figure 8. RNLAF pilot flying the demonstration

In the demonstration room 4 large screens were set up right in front of the attendance. In Figure 9 an overview of the demonstration set-up is shown with the presentation screens in the middle and one cockpit at each side. On the left and right screen a duplication of all relevant cockpit displays from both cockpits were presented. The two middle screens were used for presenting an overview of the battle area. On one screen a 2D map overview of the area was given with the positions of all real and synthetic players. The other screen was used for a visualization tool that presented a real-time, 3D perspective of the battlefield. This complete set-up provided the attendees the opportunity to follow in real-time the demonstration scenarios and to watch exactly what ET symbology was presented in the cockpit.

Figure 9. Overview of demonstration set-up

The demonstrations were attended by a range of different stakeholders: technicians, representatives of the US Air Force and US Navy, F-16 and F-18 user communities, leadership, and external organizations. The attendants were divided into 3 groups. Each group started with a presentation in which the Embedded Training concept was explained with a focus on their needs. The presentation was followed by a demonstration of five, in complexity increasing scenarios. This demonstration was followed by an interactive discussion between the attendants, the RNLAF pilots and the Dutch Space / NLR team. A side session was held where integration of the ETS in the current planning tool PFPS/FalconView was explained by a hands-on demonstration.

CONCLUSIONS AND RECOMMENDATIONS

NLR and Dutch Space have demonstrated the viability of ET for F-35 Lightning II pilots flying multiple aircraft. The demonstration at Lockheed Martin in Fort Worth, Texas, was attended by pilots from the United States and F-35 participant nations, as well as F-35 technical personnel. The demonstration successfully provided these different stakeholders with the awareness and understanding of Multi-Ship ET needed for further refinement of the F-35 ET requirements. Additionally it demonstrated the many benefits ET provides to the training continuum and the need for Multi-Ship ET to "train as we fight".

The main conclusions and recommendations with respect to ET that can be drawn after this ET multi-ship demonstration and the previous ET projects and studies are:

- multi-ship embedded training is feasible
- technology is mature for implementation on-board fighter aircraft
- dedicated Simulation Data link is essential for synchronization of ET scenarios
- extensive cost savings and improved quality at low investment cost
- mix of AACMI and ET scenarios is an option

The images of the monitor and debrief displays evidently illustrated that many ETS generated synthetic players can be added to a real life training mission, allowing fighter pilots to train their multi-ship tactics in a realistic manner and at very low cost.

Further the demonstration proved that NLR's F4S is a very useful and flexible research facility for developing new concepts for modern fighter aircraft. It provides the operational users in an early phase with data and hands-on experience necessary to refine functional requirements of new systems and concepts.

ACKNOWLEDGEMENTS

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REFERENCES

Keuning, M (2007). *Low-Cost Fighter 4-Ship Simulation for Research on Effective Team Training*, International Training Exhibition and Conference ITEC, Cologne, Germany, April 2007

Krijn, R. and Wedzinga, G. (2004). *Development and in-flight demonstration of 'E-CATS', an experimental embedded training system for fighter aircraft*, 35th Annual International Symposium of the Society of Flight Test Engineers, Wichita, KA, USA, September 2004

Stokkel, F. and Wegkamp, E.J.A. (2006). Advantage confirmed, *ETS News, spring 2006,* pages 64-66