Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

NLR-TP-2004-393

Development and in-flight demonstration of 'E-CATS', an experimental embedded training system for fighter aircraft

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This report has been based on a paper presented at 35th Annual International Symposium of the Society of Flight Test Engineers, Wichita (Kansas), U.S.A., 13-17 September 2004.

Customer:	National Aerospace Laboratory NLR
Working Plan number:	ASA.1.A.2/ASA.1.C.2
Owner:	National Aerospace Laboratory NLR
Division:	Aerospace Systems & Applications
Distribution:	Unlimited
Classification title:	Unclassified
	October 2004

Approved by author:	Approved by project manager:	Approved by project managing department:
15/10/04	15/10/04	18/10

Summary

An Embedded Training (ET) System (ETS) for fighter aircraft is a system installed in an operational fighter in order to train the pilot while operating the aircraft in a situation where it was designed for, but which is not available in every day life. Such a system is intended to overcome a number of problems inherent to the traditional in-flight mission training that requires both ‘red and blue air’ flights and the availability of Surface-to-Air Missile (SAM) sites on the ground. Examples of such problems are limitations of training hours and flights due to budget constraints, limited availability of training space, especially for Beyond Visual Range training in Europe, and scarce availability of SAM threats. An ETS can overcome this by generating in real flight virtual surface-to-air and air-to-air threats to the pilot, who, unlike when training in a ground mission simulator, will still experience the full dynamics of real flight.

Under a contract with the Netherlands Department of Defence and the Royal Netherlands Air Force (RNLAF), an ETS (called ‘E-CATS’) was developed to demonstrate the feasibility of current technology for implementing ET capabilities in fighter aircraft. The development was a co-operation of the National Aerospace Laboratory NLR and the Dutch Space company[1]. For obvious reasons of availability, an RNLAF F-16 was chosen as target aircraft, but the idea is applicable to modern fighters in general. The system was designed to inject the virtual threat signals straight into the mission system of the F-16 to enable the pilots to experience the full realism of interaction with the standard aircraft systems. Additional computer systems have been installed in the F-16 to manage the simulations, run the threat models, and perform the interaction with the aircraft systems. Safeguarding measures have been implemented. Both a training scenario generation tool and a debriefing facility are available. The project started mid 2003. System design, development and integration in the aircraft took nine months, taking advantage of an earlier flight simulator based application. In April 2004, a series of demonstration flights with pilots from RNLAF, Lockheed Martin, and the JSF Program Office completed the project.

The paper describes the requirements for the ETS. It discusses its functional concept and system architecture, its development and the test methods applied. The findings of the pilots and possible future enhancements are discussed. The evaluation results proved that ET as implemented in E-CATS has considerable value for a variety of training objectives related to Beyond Visual Range tactics. It is concluded that the project has contributed considerably to an increase of the maturity of ET technology.

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[1] Dutch Space BV, P.O.Box 32070, 2303 DB Leiden, The Netherlands, www.dutchspace.nl

List of acronyms and abbreviations

AIFF	Advanced Interrogation Friend or Foe
BRA	Bearing Range Altitude
BVR	Beyond Visual Range
E-CATS	Embedded Combat Aircraft Training System
ET	Embedded Training
ETCS	Embedded Training Computer System
ETRG	Embedded Training Radar Gateway
ETS	Embedded Training System
EWMS	Electronic Warfare Management System
EUCLID	European Co-operation for the Long term Defence
FCR	Fire Control Radar
GCI	Ground Control Intercept
HUD	Head Up Display
JPO	JSF Program Office
JSTAB	JSF Science and Technology Advisory Board
MFDS	Multi Function Display System
MLU	Mid Life Update
MMC	Modular Mission Computer
NLR	National Aerospace Laboratory NLR
NM	Nautical Mile
OSB	Option Select Button
RNLAF	Royal Netherlands Air Force
RTB	Return To Base
RWR	Radar Warning Receiver
SA-6	Short range SAM
SA-10	Long range SAM
SAM	Surface to Air Missile
TWS	Track While Scan
WVR	Within Visual Range

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1 Introduction

Embedded Training (ET) can be defined in general as a built-in capability of an operational system that enables the operator to use the system in a situation that it was designed for while that situation is not actually available. More specifically for fighter aircraft, ET allows pilots to train intensively and realistically by immersing them into a mission scenario augmented with synthetic (or virtual) entities with which they can interact (Fig. 1). As a result, the pilot is able to utilise his aircraft ("ownship") to its full capability and to engage large numbers of air and ground threats in challenging scenarios.[2]

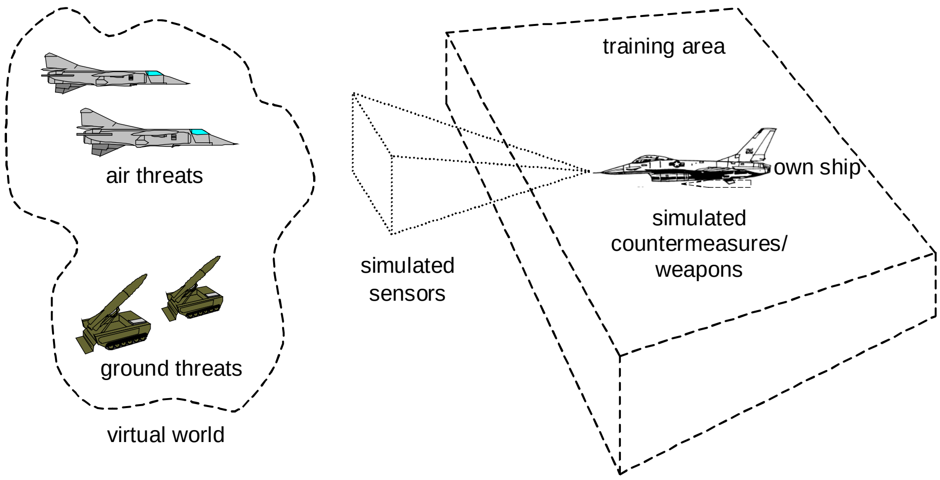


Fig. 1. Embedded Training in a fighter aircraft.

The pilot interacts with the virtual threats by using his (unmodified) cockpit controls and displays. For example, he may perform identification, fire weapons, and apply countermeasures. Effectiveness of countermeasures is also realistically simulated. Virtual threats will show a realistic intelligent behaviour. For example, they fire missiles at the real aircraft and apply countermeasures when they are attacked.
As a result, ET comes as close as possible to real combat missions. Application of ET gives rise to several direct advantages:

1. Cost reduction. In live combat training without ET, real aircraft act as the enemy. These so-called 'red air' flights are costly, and obviously provide only limited training value for the

[2] Embedded Training for combat aircraft can be applied in single-seat aircraft, as well as in dual-seat aircraft. Although not excluded, an instructor is not required on board of the aircraft during the training exercise.

pilots flying them. With budgetary constraints on flight hours, ET as a mere ‘red air replacement’ will be very cost effective.

2. The relatively small volume of airspace needed. Many of today’s and future air-to-air engagements are Beyond Visual Range (BVR). Detection of the enemy, identification, weapon delivery, and electronic warfare all take place at relatively long distances between the players. In live combat training of BVR engagement, training areas are needed as large as 100 x 100 nautical miles (NM). With ET, however, significantly smaller designated areas are needed, simply because only space for the real aircraft is required. Since airspace for military training is scarce, particularly in Europe, ET will give significant logistics advantages.
3. Realistic simulation of ground threats. In current tactical combat training, participation of realistic ground threats, such as Surface-to-Air Missiles (SAM), is expensive and sometimes technically not feasible. ET technology, however, has the potential of realistic simulation of ground threats. Moreover, ground threats can be replicated as many times as needed and can be positioned at any location, even at sea.
4. Flexible simulation of air threats. Virtual, as opposed to real red air aircraft, can be given any characteristic, thereby increasing the number of possible training scenarios.
5. There is also a security benefit. Since the red air flights are virtual flights, a less friendly observer isn’t able to deduct the whole tactics picture from watching the training effort.

Other benefits include real-time feedback to the pilot (‘wounded’, ‘killed’, etc.) and easy post-flight evaluation of training results.

The history of the development of ET technology for fighter aircraft at the National Aerospace Laboratory NLR dates back to the mid-1990s when NLR and Dutch Space participated in a European long-term strategic defence program (EUCLID) to assess the feasibility of ET for fighter aircraft. The outcome of this study formed the basis for development of an ET system, which has been demonstrated in July 2003 on the AerMacchi MB 339 advanced trainer aircraft. This aircraft is not equipped with a mission system. Addition of the ET system therefore required limited integration with existing on-board systems [1]. In the meantime, in a national Netherlands program, NLR and Dutch Space designed and implemented an ET software module on an F-16 MLU flight simulator, which has been demonstrated in August 2000. It proved the concept of ET, and identified the benefits for operational use. In June 2003, NLR, Dutch Space, and the Royal Netherlands Air Force began a joint effort to develop an ET demonstrator system, to install it in an F-16 combat aircraft, and to execute a flight program for demonstrating embedded training capabilities. This ET demonstrator system was named **E-CATS**, which stands for **Embedded Combat Aircraft Training System**. The main objectives of the project were to demonstrate the maturity of the Dutch ET concept, and to gain insight in the integration of ET with the mission systems of an operational fighter aircraft, e.g., an F-16.

In Chapter 2 of this paper, the requirements imposed on E-CATS, including development constraints and limitations and the operational scenarios to be supported are addressed. Chapter 3 continues with an overview of the system concept and architecture. Next, Chapter 4 presents the system design, and Chapter 5 is about installation and testing. A typical training mission with E-CATS is described in Chapter 6. Chapter 7 describes how it has been demonstrated and evaluated. Finally, Chapter 8 offers some conclusions.

2 Requirements and limitations

In this chapter the operational scenarios that have to be supported are described, as well as the most important development constraints and system limitations that E-CATS has to comply with.

2.1 Operational Scenarios

Two operational scenario types have to be supported by E-CATS: a ground-to-air scenario and an air-to-air scenario. These two scenario types may be trained in combination as well.[3]
For composing a Ground-to-Air scenario two types of SAM-sites are available. These are the Russian SA-6 and SA-10, which can be positioned at a number of arbitrary locations. These ground threats search, detect, track, and fire missiles at the ownship. The Radar Warning Receiver (RWR) gives audio search indications, as well as track and launch indications. Threats are displayed by an appropriate symbol on the RWR Azimuth Indicator, which is part of the Electronic Warfare Management System (EWMS). The position of the symbol indicates the location of the threat with respect to the ownship. Defensive actions, such as chaff and beaming may result in break-lock of the SAM's radar, and then the RWR indication will stop. The missile closest point of approach is computed and the ownship damage will be determined using concentric rings of probability-of-kill. The most inner ring will result in a kill notification, the middle ring in a wound notification, and outside these rings means survival.

An Air-to-Air scenario consists of a hostile two-ship (Russian SU-27 Flankers) and a friendly two-ship that returns to base (RTB). Ground Control Intercept (GCI) gives an air-picture in Bearing Range Altitude (BRA) with respect to a predefined position (bullseye). GCI calls are

[3] Note that the system does not support air-to-ground scenarios in which ground targets need to be eliminated by using precision weapons.

made once per minute. When an entity is within 15 NM of the ownship, no further GCI calls are made for that entity. A virtual entity will appear on the radar display if the radar set-up covers its position, and if the entity is within detection range. The hostile two-ship will deploy long range missiles (AA-10C Alamos). Just as for ground threats, the RWR will provide indications for the air threats. The use of chaff and beaming may again result in radar break-lock. The impact of incoming missiles is determined likewise as for the ground-to-air scenario. The ownship can eliminate hostile aircraft by simulated firing of missiles. In this case only two damage results are possible: kill or miss.

2.2 System Limitations

As a result of development time and budget constraints, several limitations were accepted for the functions provided by E-CATS. The most important ones are:

1. Embedded training scenarios with only one ET-equipped aircraft ("single-ship") will be supported.
2. Virtual entities and real entities will not be mixed on the radar display. While no simulation is running, the radar display shows real entities, and after a simulation is started, only virtual entities are shown.
3. No identification interrogation will be provided for virtual entities. Consequently, threat identification (ID) will have to be contained in the GCI calls.
4. GCI will only make periodic calls giving the location, heading and identity of each group of virtual entities.
5. Within Visual Range (WVR) engagements will not be supported. ET WVR engagements require that a visual image of virtual opponents can be superimposed on the outside world as seen by the pilot. Helmet Mounted Displays or other displays suitable for realistic visualisation of virtual opponents in the outside world as seen from the fighter cockpit do not yet exist.

2.3 Development Constraints

Since E-CATS will be an experimental system that will be installed in an F-16 aircraft for a limited period of time, some specific constraints governed its development:

1. All aircraft systems have to remain operational. For example, none of the systems should have to be removed from the aircraft to obtain installation space.
2. Without E-CATS installed, all aircraft systems should function normally. For safety reasons, the same requirement applies with E-CATS installed and its power switched off.
3. After completion of the E-CATS flight demonstration program, it should be possible to bring the aircraft back to its original state, as if no modifications were ever made. This constraint

implied that it was not allowed to cut any of the existing aircraft wiring, but that existing (unused) cables, free (test) connector pins, and new cables had to be used.

3 System concept

3.1 Functional Architecture

E-CATS consists of an airborne and a ground segment (see Fig. 2).

The airborne segment has three main simulation modules. First, the Simulation Management module, which controls the overall course of the exercise. Second, the Ownship Simulation module, which stimulates the on-board sensors and simulates the own weapons and electronic warfare systems. Third, the Virtual World Simulation, simulating the virtual entities in the exercise. In addition a specific Safeguarding module ensures the safety of the aircraft. While a training exercise is in progress, the Data Recording module gathers all data that are needed for after-action review or debriefing purposes. The Interface Layer takes care of the communication between the simulation modules and the mission system.

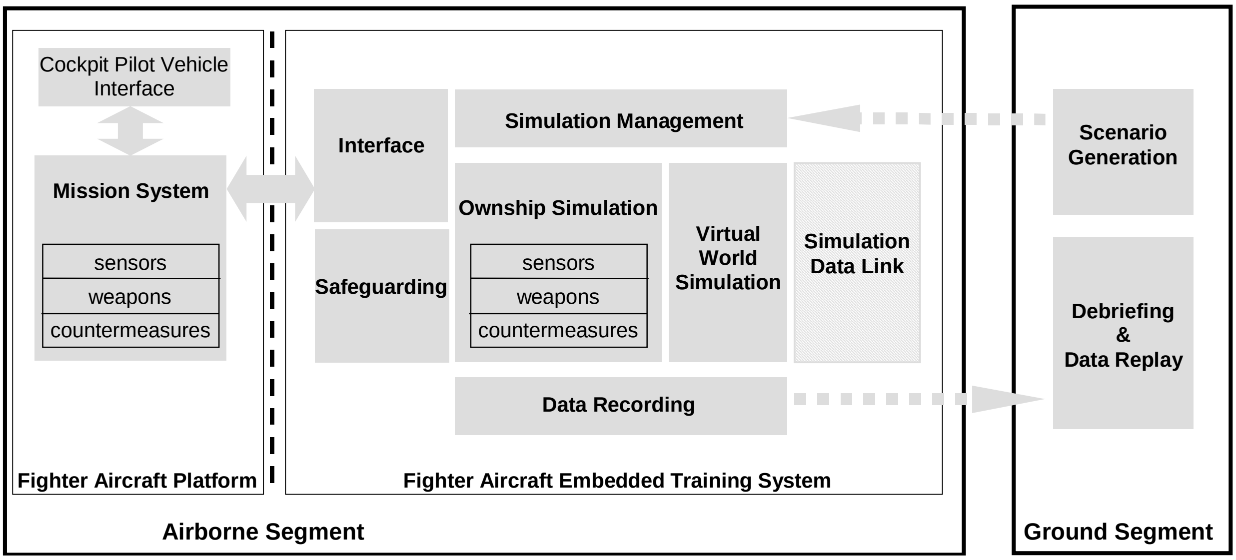


Fig. 2. Functional architecture of the E-CATS Embedded training system.

The ground segment consists of two modules: the Scenario Generation module and the Debriefing & Data Replay module.

This basic architecture is sufficient for the training of engagements in which, as required for E-CATS in its current version, one ET-equipped aircraft is involved and all other players are simulated. However, in more complex and more realistic exercises, with more that one training aircraft taking part, an airborne data link between the training aircraft is needed to ensure that all players have matching virtual world information. In that case a *Simulation Data Link* module has to be added.

3.2 Airborne Segment

During the exercise, the *Simulation Management* module performs functions such as selecting training scenarios, starting and stopping training exercises. In addition, this module controls the recording of the exercise.

The *Ownship Simulation* includes models of the aircraft systems that are relevant for ET. Ownship Simulation includes models for the fire control radar, the loaded missiles, chaff, and the radar-warning receiver. Another part of the Ownship Simulation is a realistic assessment of hostile weapon effectiveness, including hit calculation and probability of kill. Data is sent to the system displays in the cockpit as if real threats were present.

The two modules Ownship Simulation and Simulation Management maintain an intensive two-way communication with the aircraft's mission system. The mission system handles sensor data, weapon data, and electronic warfare data. Each time the pilot gives an input to one of the cockpit systems, the simulation is updated and the resulting new simulation data are fed into the mission system.

The *Virtual World Simulation* includes the virtual ground and air threats, their weapons, and dynamic behaviour, involving strategies, tactics, manoeuvres, and countermeasures. A simulated Ground Control Intercept (GCI) is included as part of the virtual world. It verbally provides the pilot with an air picture.

In case of severe safety risks the *Safeguarding* module automatically shuts down the execution of the training scenario to allow the pilot to regain situational awareness of the real world. Safety risks covered by that module include the inadvertent crossing of the boundaries of the reserved airspace by pilots immersed in ET or inadvertent arming by the pilot of the missile weapon system with the risk of firing a real missile at a virtual threat. Another potential risk, not yet monitored by the safety layer, is when the aircraft enters unsafe flying conditions like a severe low speed situation and the pilot needs all his attention to keep control of the aircraft.

3.3 Ground Segment

By means of the *Scenario Generation* module the individual scenarios can be developed. Up to 5 preselected scenarios can be combined into one set for the planned exercise. After verification of the scenarios, the digital representation of the set of scenarios can be loaded in the aircraft.

The *Debriefing* module is used for replay for post-flight debriefing and evaluation purposes. It provides the pilot and his instructor with an interactive tool for replay of in-flight recorded data that generates a synchronised re-presentation of the HUD- and MFD-display, the aircraft flight tracks and an event list.

4 System design

The description of the E-CATS design in this section focuses on the integration with the mission system of the F-16 aircraft.

4.1 System Architecture

In Fig. 3 the system architecture is depicted; only the aircraft systems and connections relevant to E-CATS are shown. The Modular Mission Computer (MMC) is the heart of the mission system. It acts as primary bus controller for the MIL-STD-1553B MUX-buses. The units shown in the top row of the figure are part of the cockpit pilot vehicle interface. The two grey blocks represent the units that together form the E-CATS electronics, i.e., the Embedded Training Computer System (ETCS) and the Embedded Training Radar Gateway (ETRG). To exchange information, these two units are connected by means of an Ethernet link (ETRGLINK).

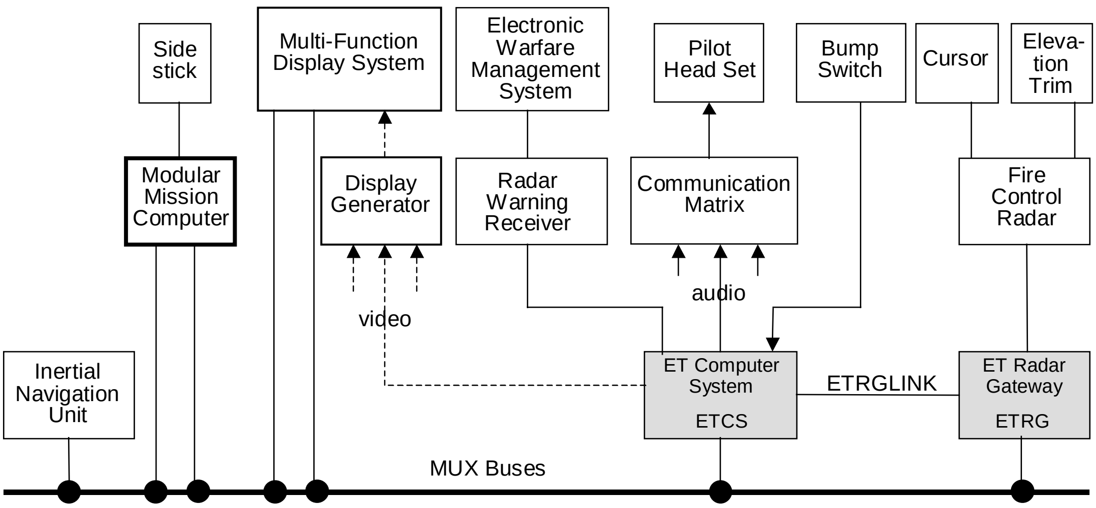


Fig. 3. System architecture of E-CATS.

The *ETCS* is a PowerPC-based platform running an Embedded Linux operating system and the EuroSim simulation engine [2]. The ETCS is installed in the centreline pylon under the aircraft. The execution of all embedded training simulation software takes place in the ETCS.

The *ETRG* is also a PowerPC-based platform, but it runs the VxWorks real-time operating system. The ETRG is installed in a tray designated for the future installation of a Helmet Mounted Display interface unit. The main function of the ETRG is to inject radar observations of virtual entities into the mission system. It breaks into the connection between the Fire Control Radar (FCR) and one of the MUX buses ("break-in mode"). When the ETRG power is switched off, or when no simulation is running, it reconnects the FCR with the MUX bus directly ("transparent mode"). When the ETRG is removed from the aircraft, it is replaced by a "Dummy-ETRG" that connects the FCR to the MUX bus to enable normal operation.

4.2 Integration with Fire Control Radar

The Fire Control Radar (FCR) is the primary target detection sensor of the F-16. The FCR converts the radar data into a digital format, and presents the pilot with a synthetically generated image made up of a set of predefined symbols. The pilot may select different radar operating modes. The integration of E-CATS with the radar processing chain is based on the use of the Track While Scan (TWS) mode of the FCR. In this mode, the FCR transmits target observations in message blocks through the MUX bus to the Multi Function Display System (MFDS) and the Modular Mission Computer (MMC).

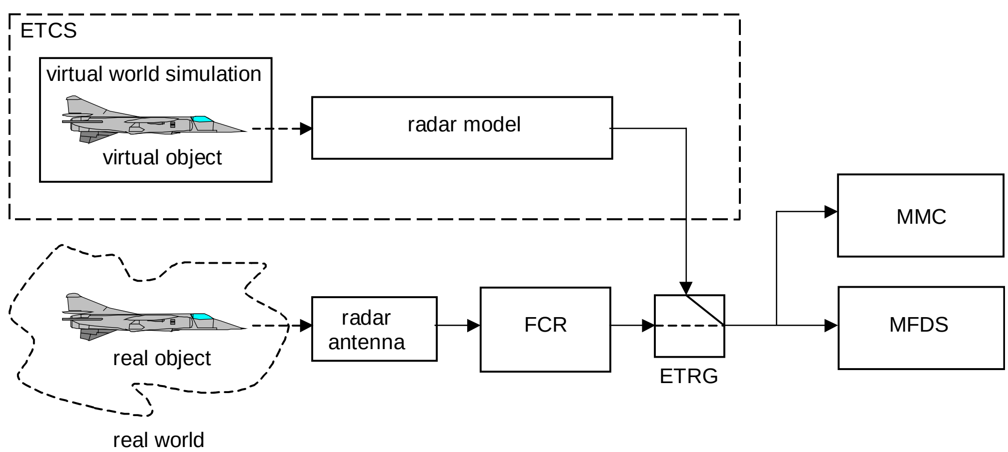


Fig. 4. Fire Control Radar interfacing.

As can be seen from Fig. 4 the ETRG operates as a switch with two states controlled by the ETCS. When no simulation is running, it connects the FCR (through the MUX-bus) with the MFDS/MMC, and observations of real objects are displayed on the MFDS. When a simulation is running, the ETRG connects a model of the radar system (executed by the ETCS) with the MFDS/MMC, and observations of virtual objects are displayed on the MFDS. As a result, it is not possible to mix real world observations with virtual world observations. This is acceptable, because E-CATS supports only single-ship operation, and the ownship is the only real aircraft present in the training area. [4]

4.3 Integration with Radar Warning Receiver

The Radar Warning Receiver (RWR) monitors the radar environment to alert the pilot of any hostile or foreign activity that may be taking place. When it receives a radar signal a graphical symbol representing the type of radar and its relative location is displayed on the Azimuth Display of the Electronic Warfare Management System (EWMS). If the system determines that the radar is an immediate threat, it gives a distinctive audible warning.
The RWR has an auxiliary input port for external injection of symbol identifiers and symbol positions on the Azimuth Display (Fig. 5). A model of the RWR (executed by the ETCS) determines the symbols to be displayed depending on the radar activity of the virtual entities (air threats and ground threats). This information is fed into the auxiliary input port of the RWR. The symbols associated with virtual entities are superimposed on the symbols generated from real entities.

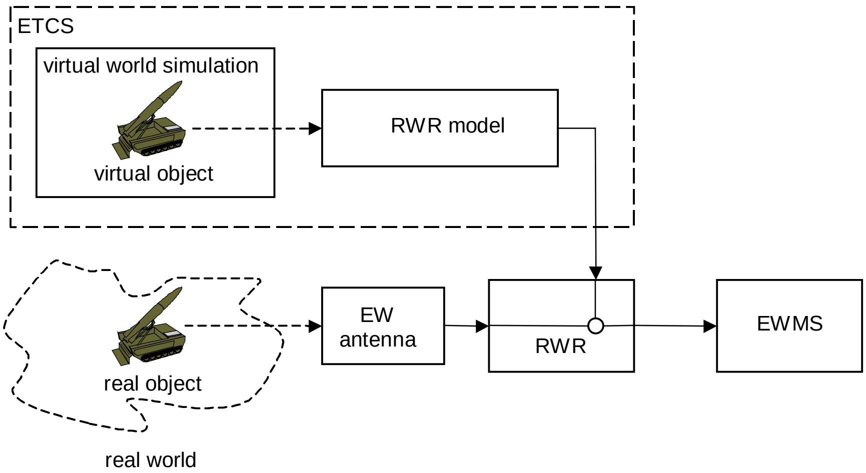


Fig. 5. Radar Warning Receiver interfacing.

Since the RWR generates search and track audio cues directly from the received radar signals, such audio cues cannot be generated for virtual entities. The solution has been to store digital samples of relevant audio cues in the ETCS, and to play these sounds on the pilot's headset when appropriate.

[4] General flight safety requirements do not impose that the FCR should be operational while embedded training is taking place.

4.4 Integration with Weapons and Countermeasures

The pilot can deploy missiles to eliminate hostile aircraft. The MMC transmits a message block over the MUX bus containing an indication of missile launch and other relevant parameters associated with it. The ETRG continuously monitors this message block, and forwards it to the ETCS. The 'missile-launched' indication is used to trigger the execution of the missile model within the virtual world simulation (executed by the ETCS).

The pilot can dispense chaff as a countermeasure to incoming missiles. Of the different buttons available to the pilot for dispensing chaff, the bump switch is wired to the ETCS. The ETCS executes a model of the chaff-dispensing unit, which maintains its own count of the remaining amount of chaff. When the pilot hits the switch, an audio message is played on his head set, i.e., “chaff/flare” (if sufficient chaff is available), “low” (if the amount of chaff is less than 25% of the initial amount), or “out” (if there is no more chaff available). The missile models executed by the ETCS evaluate whether dispensed chaff will lead to a radar break-lock or not.

4.5 System Control

During flight embedded training scenarios need to be selected, started, and stopped. A specific page on one of the two displays of the MFDS is used to control E-CATS. The layout of the control page is shown in Fig. 6. Of the twenty Option Select Buttons (OSBs), mounted in the bezel of the display, OSBs 6-10 and 18-20 are used for E-CATS control. Four-character labels are displayed near each OSB. The labels displayed at OSBs 6-10 represent up to five choices for embedded training scenarios. The labels RUN, STOP, and CLR can be displayed at OSB 20,18 and 19 to start and stop simulations, or to cancel a selection.

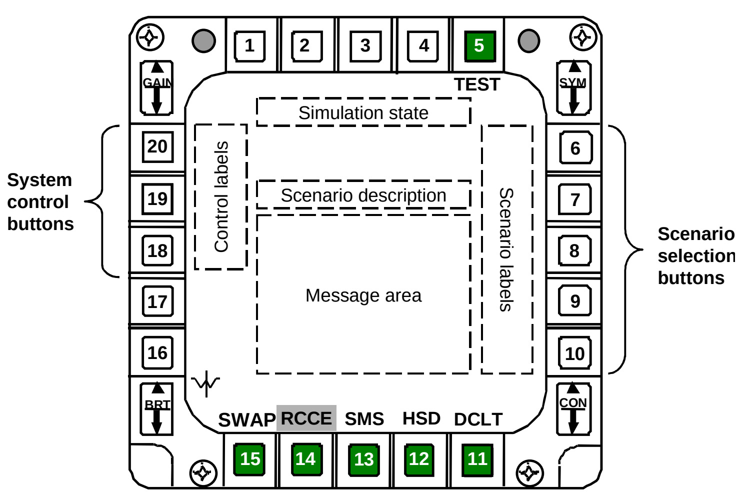


Fig. 6. Layout of E-CATS control page.

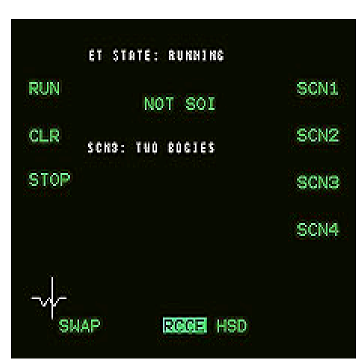


Fig. 7. Scenario 3 running.

The central area of the display consists of three fields. The 'Simulation state' field is used to display the system state, e.g., “ET STATE: RUNNING”. The 'Scenario description' field gives a one-line description of the selected scenario, e.g., “SCN3: TWO BOGIES”. The 'Message area' field gives further relevant information, e.g., why the simulation has stopped (e.g. “STOPPED BY PILOT”). Changes in the simulation state are accompanied by voice messages on the pilot’s headset. Fig. 7 gives an example of the control page with a scenario running.

Fig. 8 depicts the flow of the control information. The ETCS transmits a message block on the MUX bus that contains the labels for each OSB. The MFDS positions these labels at the appropriate locations on the display. The ETCS also produces a video overlay for the central area of the display (Simulation state, Scenario description, and Message area fields). The video signal is connected to an input of the Display Generator, which connects the signal to the MFDS display that shows the E-CATS control page. The MFDS transmits a message block that identifies an OSB depression by the pilot. The ETCS receives this message block, and processes it accordingly.

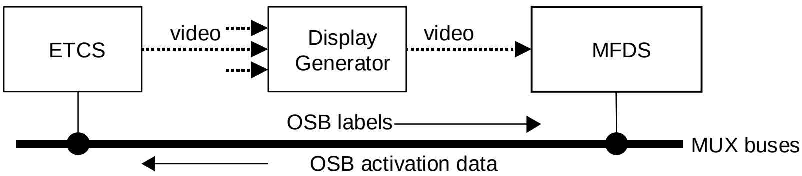


Fig. 8. Exchange of control and status information.

5 Installation and test

The installation and test phase consisted of six stages: (1) environmental testing of the hardware, (2) functional laboratory testing at unit and system level, (3) aircraft modification testing, (4) on-ground system testing, (5) Safety-of-Flight test, and (6) flight tests.

First, the two E-CATS units were subjected to environmental tests. The ETCS consists of a mix of components qualified for military environments and industrial components that have been ruggedised to withstand the harsh environment in combat aircraft. The ETCS was subjected to EMI tests, shock and vibration tests, temperature and pressure tests, and power tests. The ETRG is a commercially available unit that meets environmental requirements for military applications. The ETRG has only been subjected to EMI tests in order to evaluate the impact of tray mounting and cable connections.

Next, functional tests at unit level and system level were executed in a laboratory environment using simulated aircraft systems. These tests involved checking the interfaces of both units (MUX buses, audio, video, Ethernet, and discretes). Also, basic functional tests were executed. For the ETCS, these tests included system control, safety and start conditions, SAM-6/10 functions, RWR interfacing, behaviour of virtual aircraft (hostile as well as friendly), behaviour of missiles, effect of chaff release, and behaviour of GCI. For the ETRG, functional tests included a check of the two operational modes ('transparent' and 'break-in') and the capability to switch between these modes. System tests were executed to verify the combined operation of ETCS and ETRG.

Fig. 9. Mounting of the centreline pylon with ETCS.

Fig. 10. ETRG installed in aft avionics compartment.

After completion of the aircraft modification, specified in accordance with RNLAF F-16 regulations, all modified and new wiring was checked, and signal levels were recorded, first with the E-CATS units not installed (but with Dummy ETRG), and then with the units installed (Fig. 9 and 10). Signal levels were checked against measurements before the aircraft modification.

Next, on the ground integration tests were executed with the system installed in the aircraft (Fig. 11). The tests evolved from simple checks of the E-CATS interfaces with the aircraft systems involved to conducting more complex, but 'static', embedded training missions for checking ground-to-air, air-to-air scenarios, as well as combined scenarios. This phase was completed by performing, before the start of the flight tests, a so-called 'Safety-of-Flight' test to check the undisturbed functioning of the basic aircraft systems with the complete system installed and its power switched on.


Fig. 11. Integration testing

Finally, some 20 flights were performed over a three months period with gradually changing emphasis from basic in-flight functional testing to the fine tuning of the simulation models taking into account the findings of the pilots before the system was found ready for the demonstration flights.

6 Training mission

A training mission with E-CATS consists of three phases: *mission preparation*, *mission execution*, and *mission evaluation* (Fig. 12). The activities in these phases are described in more detail in the following subsections.

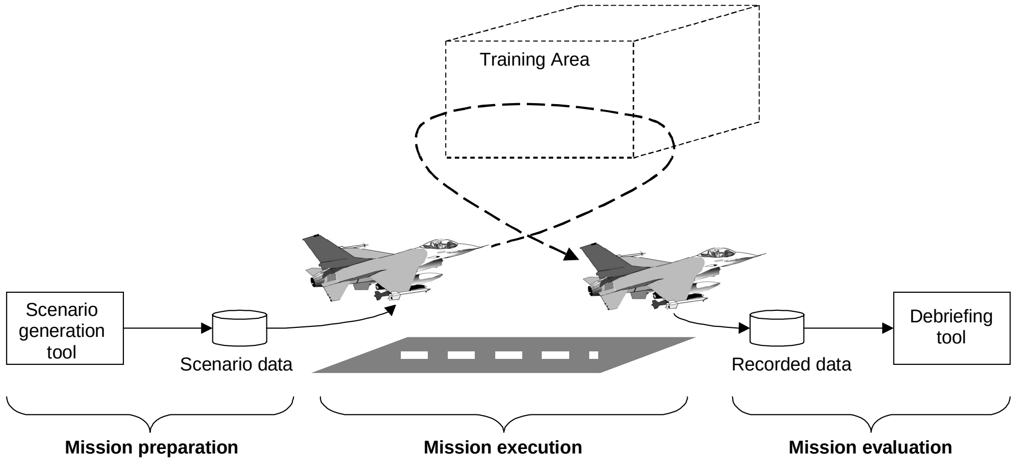
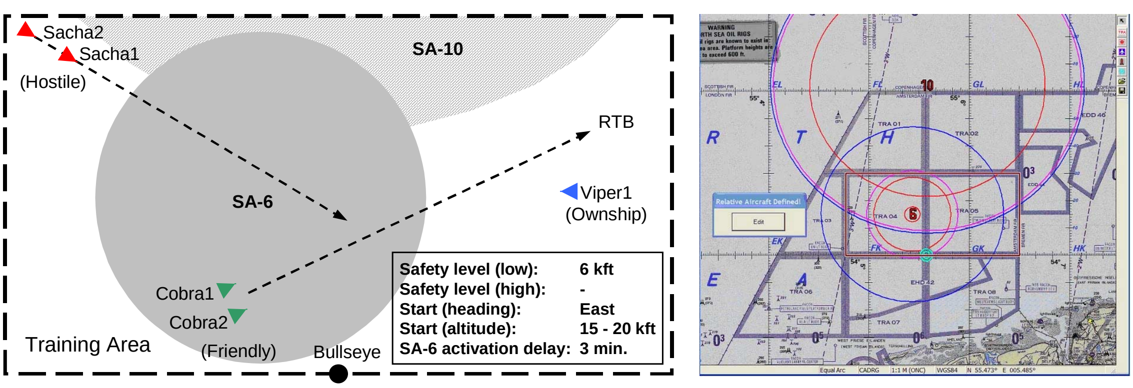


Fig. 12. Phases of an E-CATS training mission.

6.1 Mission Preparation

From the pilot point of view, preparation for an E-CATS training mission will be the same as for any normal mission. Using existing mission planning systems, input data like target data, intelligence data, and meteorological data are analysed and transformed into data for use on-board.

E-CATS training missions require one additional step, i.e., the preparation of data that define the actual situation to occur during execution of the training mission (the training scenario). This is an instructor function. It involves definition of parameters for virtual entities, including locations of SAM-sites and types, routes and tactics followed by hostile aircraft, and routes of friendly aircraft. Also the training area and the scenario entry conditions need to be specified. Fig. 13 shows an example of a scenario that contains a combination of ground and air threats. Inside the box, some safety levels and scenario starting conditions are specified. The SA-6 is activated three minutes after the start of the scenario. Also note that the SA-10 is located outside the training area. A PC-based scenario generation tool has been developed that is built on the commercially available tool Falconview. The right side of Fig. 13 shows the screen of the tool while this scenario was created.



Note: SAM ranges are fictitious.

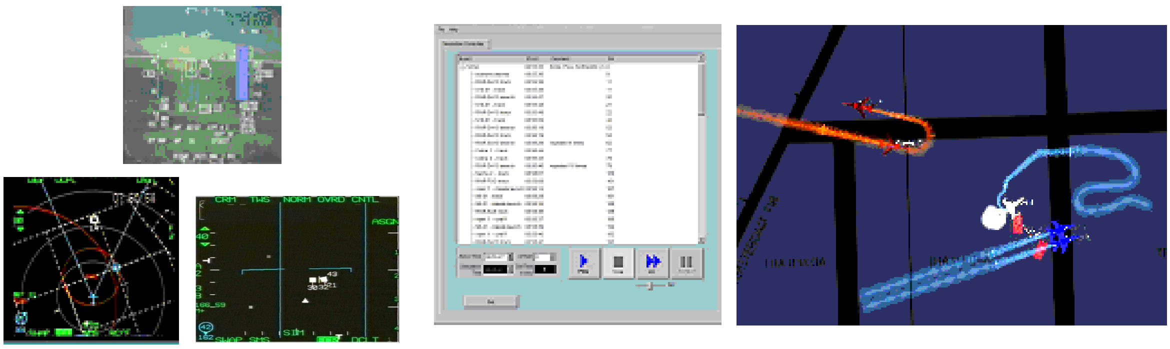
Fig. 13. Combined ground-to-air and air-to-air scenario.

6.2 Mission Execution

Upon arrival at the designated training area, the pilot can select one of the available scenarios. Only after all safety conditions and scenario entry conditions are satisfied, as announced by a voice message ("System stand-by"), the pilot can start the ET scenario. An example of a safety condition is that the aircraft should be inside the training area. An example of a starting condition is that the heading of the aircraft should be west. After starting the scenario, the pilot will be confronted with the virtual threats. While a scenario is running, E-CATS records all the necessary data to enable mission replay on the ground. The pilot can stop the scenario at any point in time, but an automatic termination of the scenario may also be performed. This may be triggered by events in the scenario (e.g. a virtual kill of the aircraft) or by safety related events (e.g. aircraft outside training area). A voice message announces that the simulation has been stopped and indicates the reason. Subsequently, the pilot may repeat the same scenario, start a new scenario, or return to base.

6.3 Mission Evaluation

To support debriefing of E-CATS training missions, a PC-based system has been developed. Fig. 14 shows the set-up of the video screens used for debriefing. The left screen shows the combined video recordings of the left and right MFDS displays and the Head Up Display (HUD). These recordings are made as normal practice during every mission. The right screen shows a top view of the training scene as it is generated by replay of the recorded data. It is generated by a specific 3-D Stealth display application (notice that this particular screen shot was made during the execution of the scenario depicted in Fig. 13). Replay can be performed at speeds up to 5x real-time. The centre screen shows a list of events that occurred during the training mission, such as start and stop of simulation runs, deployment of countermeasures, missile launches and kills. The event list allows a fast stepping between events that occurred during the training session. Synchronisation between all screens is maintained while using fast replay, or stepping from event to event.



HUD (top) and MFDS displays | Event list | Top view of aircraft tracks

Fig. 14. E-CATS debriefing set-up.

7 Demonstration and evaluation

In the week of 4-8 April 2004, an E-CATS demonstration program was carried out at the airbase Leeuwarden of the Royal Netherlands Air Force. A group of six pilots and six system engineers from both the JSF Program Office (JPO) and Lockheed Martin Aeronautics Company was invited to participate in the event. Three Dutch pilots acted as hosts.

7.1 Demonstration Programme

During the first day, presentations were given about embedded training in general and about the capabilities and limitations of E-CATS. Four training scenarios for the demonstration flights were presented:

1. Surface-to-air scenario including a SA-6 and a SA-10 site. This scenario was used to show SAM-site behaviour, RWR indications, effect of defensive reactions, effect of countermeasures, and E-CATS safety features.
2. Air-to-air scenario 1: a hostile two-ship making an azimuth-split presentation. This scenario was used to show the radar displays, GCI calls and virtual threat formations and manoeuvres.
3. Air-to-air scenario 2: a hostile two-ship making a lead-trail presentation. This scenario was used to show basic engagement tactics.
4. Combined scenario (see Fig. 13). This scenario was used to highlight all the virtual interactions with the aircraft and to demonstrate increased workload.

During the following three days, a total of 8 training missions were executed; each consisting of a briefing, the demonstration flight, and a debriefing. Each flight took approximately one hour, and was flown with a Dutch pilot in the front seat and either a guest pilot or engineer in the back seat. Embedded training was conducted in an area over the North Sea. First, the Dutch pilot demonstrated the system by flying each of the four scenarios. Then, the back seat pilot could fly various combinations of the scenarios for the remainder of the mission.

7.2 Participant Feedback

After his flight each guest pilot provided ratings on the degree of realism, the effectiveness and the overall training value of training with E-CATS on a 1 to 5 points scale. Concerning the *realism* (Fig. 15) participants rated enemy behaviour, radar system, and weapons systems as very realistic (average > 4).

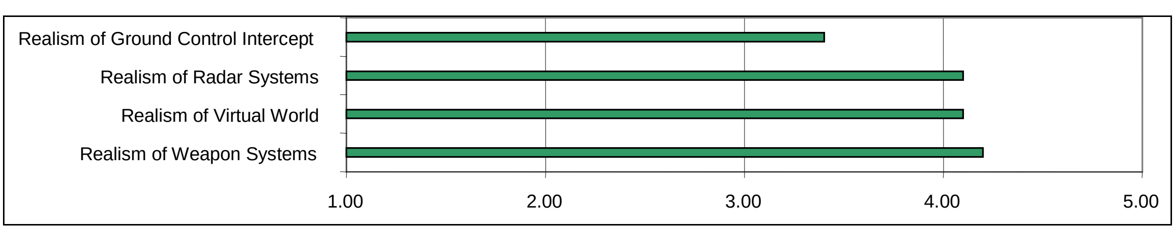


Fig. 15. Perceived realism of the E-CATS system.

Participants were least positive about the realism of GCI (average 3.4 points). One of the shortcomings of GCI was that it reported the exact positions of the virtual aircraft, whereas in reality there may be inaccuracies in the GCI reported positions. Nevertheless they still found the basic GCI feature very useful, and preferred it to not having GCI.

Concerning the perceived *effectiveness* and the *overall training value* the averaged ratings are shown in Fig. 16.

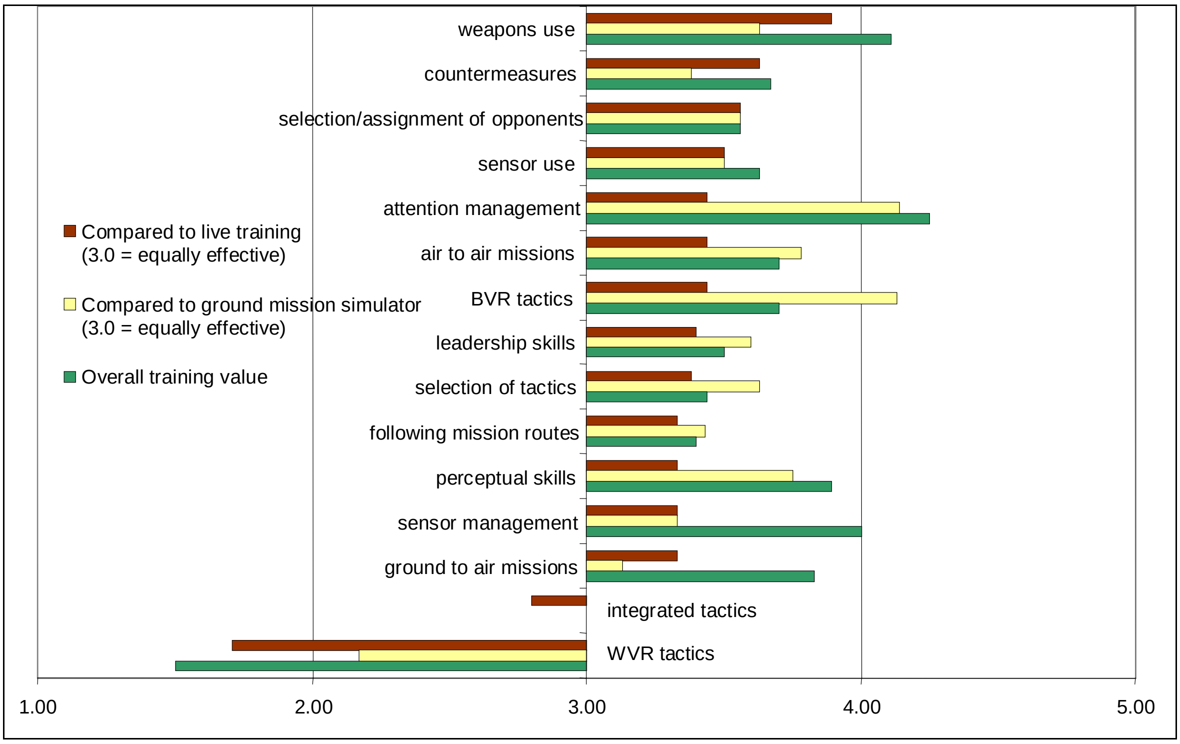


Fig. 16. Perceived effectiveness and training value of the E-CATS system.

Participants were asked to compare the effectiveness of E-CATS to live exercises, as well as to a ground mission simulator for 18 training areas. Training areas with 4 or fewer responses have been removed, i.e., low observability, team training, and lasers. Largest gain over live training is found for weapons use. Largest gain over simulator training is found for attention management and BVR tactics. E-CATS is considered not very effective for training integrated tactics and (obviously) WVR tactics. Overall training value is considered to be strongest for attention management, with a high score for weapons use too.

8 Concluding remarks

An embedded training system was developed that was interfaced to and integrated with the mission systems of an RNLAF F-16 MLU aircraft to provide training opportunities in a real aircraft against virtual threats on the ground and in the air. The functionality of this E-CATS system was limited to single-ownship scenarios in BVR situations.

From the findings of the pilots and system engineers who participated in the demonstration flights it can be concluded that embedded training as demonstrated by a relatively limited system as E-CATS has considerable training value for a variety of training areas related to BVR tactics. It was indicated that E-CATS as it is, would already provide more training value than current live training and ground-based simulator training. The system demonstrated ET potential beyond participants' expectation on most of the combat experiences supported by the demonstration scenarios.

It is believed that taking into consideration the level of integration with the operational mission system of the aircraft, E-CATS was a novelty. It meant an important step forward for the maturation of ET technology in the Netherlands, which has advanced in the last decade through European and national programmes as indicated in Fig. 17.[5]

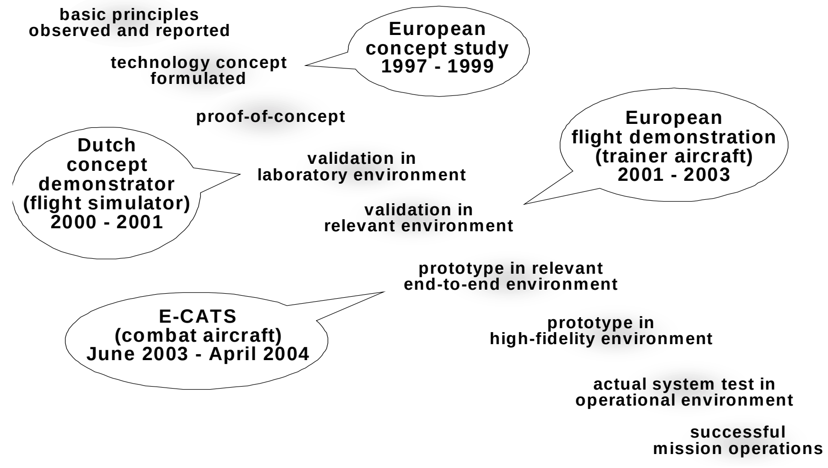


Fig. 17. ET technology maturation in the Netherlands through successive projects.

[5] Maturity levels as adopted by the JSF Science and Technology Advisory Board (JSTAB) of the JSF Program Office.

A follow-on project has been started to further increase the maturity of Embedded Training. Specific further developments are required in the areas that have been identified as current limitations, including multi-ship operation, mix of real and virtual entities on the radar display, and integration of Advanced Interrogation Friend-or-Foe (AIFF). Last but not least, there are a number of technological challenges related to these further extensions, including development of a multi-ship simulation data link and further integration of the hardware components to minimise the required space for installation.

It is expected that embedded training will in future play an important role in the training of fighter pilots for all types of BVR tactics. For new aircraft, like JSF, the integration of ET shall already have to be taken into account in the aircraft design phase, rather than thinking of ET as an add-on system.

9 Acknowledgement

This project could not have been successful without the enthusiastic co-operation and professional dedication of the employees of the Royal Netherlands Air Force at the Woensdrecht Logistics Centre and at the Leeuwarden Air Base. The organisation of the demonstration flights was in the hands of the RNLAF in Leeuwarden supported by staff members from the RNLAF headquarters in The Hague. The willingness of pilots from the JSF Program Office and Lockheed Martin to participate was crucial to the success of the demonstration programme. The authors wish to thank Dutch Space for its contribution to this paper.

10 References

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