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Self Protection EW Manager
Prototype development and demonstration

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Summary

The Self Protection Electronic Warfare (SP EW) manager is an automated system that provides a link between the available onboard EW sensors and actors in an aircraft, determines the most effective actions and, when possible, executes those actions. The National Technology Project (NTP) SP EW manager aimed to define the requirements for a SP EW manager (Phase 1) and to build a demonstrator that implements a representative subset of these requirements (Phase 2). The project was triggered by significant effectiveness improvements, obtained by the combined use of the chaff and RF jammer subsystems, as found in EW trials.

The main goal of the project was stipulated as: to develop a concept for a SP EW manager that enables co-ordinated action of the available EW assets on a flying platform, while minimising interaction with the crew. The main conclusion was that such a concept was successfully developed, and that this concept proved to be workable. However, the developed SP EW manager application is in its current form not fit for operational use, or even complete yet. It is a prototype to demonstrate the capabilities of the concept.

This paper provides a top-level description of the developed management process. This process consists of a Multi-Sensor Data Fusion part, that provides threat information to the Resource Manager. The latter selects the most appropriate countermeasure techniques for the threat situation, and schedules and executes the countermeasure actions.

In addition, an overview of the main findings is presented and discussed. It appeared that the effectiveness of the countermeasure actions largely depends on the accuracy of the (sensor)-data. Several shortcomings in the data fusion processes were identified. In the resource management part, the inclusion of aircraft manoeuvre advices proved to be a major problem, especially with regard to timing of the separate actions.

Contents

(15 pages in total)

Abbreviations and Acronyms

AAA	Anti-Aircraft Artillery
CM	Countermeasure
CMT	Countermeasure Technique
EW	Electronic Warfare
FEL	Fysisch en Elektronisch Laboratorium (Physics and Electronics Laboratory)
HMI	Human-Machine Interface
HSD	Horizontal Situation Display
ITEMS	Interactive Tactical Environment Management System
NADDES	NLR Avionics Display Development and Evaluation System
NTP	National Technology Project
MSDF	Multi Sensor Data Fusion
NATO	North Atlantic Treaty Organisation
NLR	Nationaal Lucht- en Ruimtevaartlaboratorium (National Aerospace Laboratory NLR)
POWER	Pilot Oriented Workload Evaluation and Redistribution
RF	Radio Frequency
RM	Resource Manager
RNLAF	Royal Netherlands Air Force
RNLN	Royal Netherlands Navy
RTO	Research and Technology Organisation
SA	Situational Awareness
SAM	Surface to Air Missile
SP	Self Protection
TL	Threat Level
TNO	Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek (Netherlands Organisation for Applied Scientific Research)

1 Introduction

The Self Protection Electronic Warfare (SP EW) manager is an automated system that provides a link between the available onboard EW sensors and actors in an aircraft, determines the most effective actions and, when possible, executes those actions. The SP EW manager project, funded by the Netherlands Ministry of Defence and involving the Royal Netherlands Air Force (RNLAF) and Royal Netherlands Navy (RNLN), aimed to define the requirements for such a manager (phase 1) and to build a demonstrator that implements a representative subset of these requirements (phase 2). The project was executed by the National Aerospace Laboratory (NLR) and TNO Physics and Electronics Laboratory (TNO-FEL). It started in April 1997, and the final report was delivered in October, 2000.

2 History, backgrounds

NLR has been supporting the RNLAF with the employment and optimisation of its EW assets since the introduction of EW equipment on the F-104 in the early 1970’s. From these early days on, the integration, qualification and operational testing of EW equipment on the RNLAF aircraft has been supported by NLR. This was possible by virtue of a national “add-on” capability based on the combined RNLAF/NLR competencies and facilities as well as the NLR expertise in the fields of threat system analysis, Electronic Warfare (EW) and avionics installations. This expertise materialises in (among others) the RNLAF/NLR participation in international (NATO) EW trials Mace and Embow.

In the Trials Mace V and VI in 1998/1990, the RNLAF F-16 demonstrated that significant effectiveness improvements could be obtained by a combined use of the chaff and RF jammer subsystems. To this end a so-called "Smart Box" was developed by NLR which interfaced with the antennae and Band modules of the AN/ALQ-131 jammer and the AN/ALE-40 chaff dispensers on the F-16. During the trial the effectiveness was demonstrated of the automated, co-ordinated application of chaff and jamming programs after initial detection of a radar threat.

Figure 1 NLR Smart box unit and panel

Demonstrating combined countermeasures in a controlled trial environment is one thing, creating a pseudo-autonomous system that will operate in a multiple-threat scenario, is another. This challenge was the topic of the SP EW manager project.

3 SP EW manager

3.1 Objectives

The prime goal of the project was to design and implement a SP EW Manager *concept* and to perform a "Proof-Of-Concept" demonstration. This demonstration was to be held in a laboratory environment, i.e. workstation based, and using a synthetic (threat) environment.

The original project proposal lists the following goals for the SP EW manager:

1 *To develop a concept for a SP EW manager that enables co-ordinated action of the available EW assets on a flying platform, while minimising interaction with the crew.*

2 *The SP EW manager will form the link between the available sensors and actors, will determine the most effective use [of the actors] and execute actions when possible.*

3 *Such a SP EW manager will enable co-ordinated countermeasures that cannot be executed manually using the separate systems, thus enhancing the effectivity of the EW assets and reducing crew workload.*

4 *Development of the SP EW manager concept is not limited to the manager functionality, but includes interfaces with sensors, actors and crew.*

5 *The SP EW manager concept shall be flexible, i.e.:*

   5.1 It must be platform independent.

   5.2 It must be independent of hardware characteristics of the EW assets.

   5.3 It must be independent of the number of available assets.

   5.4 It must be adaptable to the scenario (threats, constraints).

3.2 General description

The SP EW Manager consists of several distinctive parts (see Figure 2):

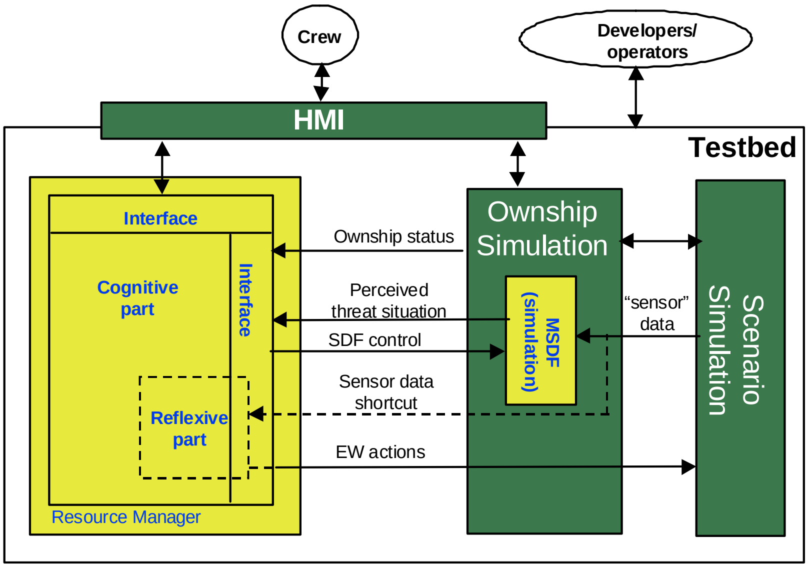

Figure 2 SP EW manager demonstrator components

- *Multi-Sensor Data Fusion (MSDF)*
  The MSDF module receives the "sensor data" from the ITEMS simulation environment (Ownship and scenario simulation, see section 3.3) and to add, modify or augment this data in such a way that a realistic evaluation of the working of the resource manager (RM) is enabled. Note that ITEMS does not really provide sensor data. Instead, it provides actual threat information the moment the threat would have been detected, based on the specified sensor characteristics. MSDF needed to add more realism, such as latency, ambiguity and inaccuracy. A "Sensor Simulation" component was included in the MSDF module to realise this.
- *Resource Manager (RM)*
  The RM module accepts the threat information from the MSDF module. Using a knowledge based technique, it selects the most suitable Counter Measure Technique (CMT), and executes the associated countermeasures. More detail on the RM processes are given in section 3.4.
- *Human-Machine Interface (HMI)*
  Development and optimisation of a Human-Machine Interface (HMI) for EW management was not part of the project. However, to be able to evaluate the SP EW manager software, a basic HMI was developed. This HMI consists of three parts:
  - a Forward View display,
  - threat and countermeasure displays,
  - throttle, stick and buttons to control the simulated aircraft.

3.3 Evaluation environment

For the demonstrator, two separate workstations were used: a SUN Ultra 60 to run the SP EW manager software. The threat environment, provided by the simulation software ITEMS, runs on a Silicon Graphics Indigo2 “Maximum Impact” workstation. The only additional hardware component was the FlyBox. Figure 3 provides a graphical depiction of the hardware components and their connections.

For the Evaluations, the SP EW Manager is linked to a simulation environment, the Interactive Tactical Environment Management System (ITEMS), built by CAE Electronics. ITEMS configures and runs a synthetic tactical environment, often referred to as an "electronic battlefield". ITEMS provide all simulated entities: ownship (including sensors), Surface-to-air threats and missiles.

Unfortunately, the simulated EW characteristics of the ITEMS players were limited. Responses to chaff and flare were modelled with sufficient accuracy, but jamming effects were only rudimentarily available. In addition, missile warning systems were not available. Therefore, the basic ITEMS software was altered to supply realistic EW responses. ITEMS does not provide a real, pulse-to-pulse, simulation of the radar. It simply checks whether or not the target reflects enough energy to be detected, using basic radar formulae. For our purposes, track box calculations and manipulation were introduced, that simulate only the *effects* of the countermeasure techniques. These calculations also account for the fact that a track signal will still be detected as long as the aircraft is in the beam, even though the track box may no longer be on the aircraft (e.g. in case of RGPO jamming). Also, each jamming technique requires a specific jam to signal ratio to be effective.

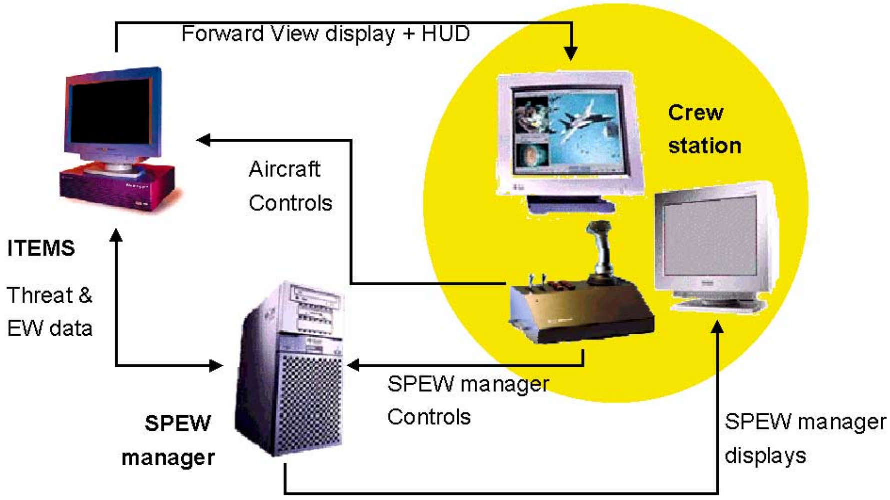

Figure 3 Demonstrator hardware components and their connections

3.4 EW Management Process

The following basic process is applied to effectively counter detected threats:

1. One or more sensors detect a signal. The signal(s) are passed to the MSDF module and to the “Reflexive” part of the RM module. If applicable, the latter will trigger an initial response.
2. The MSDF processes the incoming signal(s), trying to match them with signals from other sources and preplanned threat information. This process results in a “threat list” that is sent to the RM module. A threat is, in the applied definition, not a physical entity, but rather an instance that needs to be acted upon. For example: A SAM system’s search radar detecting the ownship will appear as a threat. Once the SAM starts tracking the ownship, a new threat is generated (the tracking radar) and depending on the SAM’s characteristics, the old threat may disappear.
   All threats in the list have the following properties:
   - Identification (+ fidelity indication)
   - Threat mode (Search, track, etc.)
   - Threat Level (TL: numeric value 1-10, corresponding with “far away search radar” – “incoming missile on MAWS”)
   - Position & Velocity (incl. uncertainty bracket)
   - For missiles: estimated time until intercept.

   If the identification is ambiguous, multiple threats will be generated, each with its own fidelity (e.g. ID1 – 70%; ID2 – 30%).
3. The RM applies a rule-based system to generate CMTs for each threat. The CMTs are stored in a knowledge-base. Each CMT consists of one or more actions: manoeuvres, jammer activation, chaff and/or flare dispense, or anything the ownship is capable of. The CMTs can have applicability constraints like aspect angle, distance, altitude, required speed or G-level. All actions inside a GMT will have associated start conditions. This can be a time since CMT start, a time since the end of the preceding action, or reaching a prescribed condition (e.g. azimuth angle to threat, G-level).
   Techniques are assigned an “effectiveness value”, that is used to select between techniques if more then one is available.
4. All selected CMTs (basically, one for each threat) are passed on to the CM scheduler. The scheduler will analyse the actions and their start conditions in the CMT and integrate them all in an overall schedule. The CMT for the threat with the highest TL will be scheduled first. If there is a conflict, the CMT is rejected. The process in step 3 will then suggest the next possible CMT for scheduling, until a working solution is found. If there are no alternatives, the same CMT is suggested, until it can be put on the schedule. Note that

execution starts when the first CMT is scheduled, so even when no alternative CMT is found, the conflict may be automatically resolved when the CMT is “re-tried”.

5. The resulting schedule is presented to the crew (see section 3.5), and in “automatic” mode, automatically executed. When manoeuvres are part of the schedule, these are “presented” via voice messages, and must be executed by the crew.
6. If a new threat with a higher threat level is detected during the execution of a schedule, and the selected CMT for the new threat uses the same resources as (one of) the running CMTs, then the running CMT will be cancelled in favour of countering the new #1 priority. The manager will try to find an alternative for the other threat as described in step 4.

This process is continuously repeated as long as the sensors are detecting threat signals. When a threat disappears from the threat list, all associated CMT actions are removed from the schedule. Soft kill assessment is provided by using the mechanism of assigning new threats on the basis of system mode. For example, if break-lock is achieved due to the applied countermeasures, the associated threat (tracking radar) will disappear. The same applies when the reflex countermeasures are effective: the threat will disappear, possibly even before a CMT can be scheduled.

3.5 Manager modes

The SP EW manager is controlled by the crew by choosing between system modes “off”, “standby” (processes running, threat information displayed, but no scheduling) or “on”. In addition, the applicable rules could be constrained by selecting one of the following “operational modes”:

- Run Silent (manoeuvres only)
- Minimum Expendables (manoeuvres & jamming)
- Minimum Jamming (manoeuvres & expendables)
- Constrained Manoeuvring (expendables & jamming)
- No restrictions

If any mode other than “No restrictions” is selected, the choice of CMTs is constrained accordingly. However, if the threatlevel exceeds 8 (i.e. illuminator or missile launch detect), all restrictions are dropped.

3.6 Human-Machine Interface

The threat and countermeasure displays were developed specifically for the project. For this development, the “NLR Avionics Display Development and Evaluation System” (NADDES) was used. The display provides a god’s eye view of the aircraft and its environment, including a time scale displaying the currently running countermeasure technique(s) (see Figure 4). The colour of the threat changes when the threat level changes (“grey” = no threat, through “red” = missile detect).

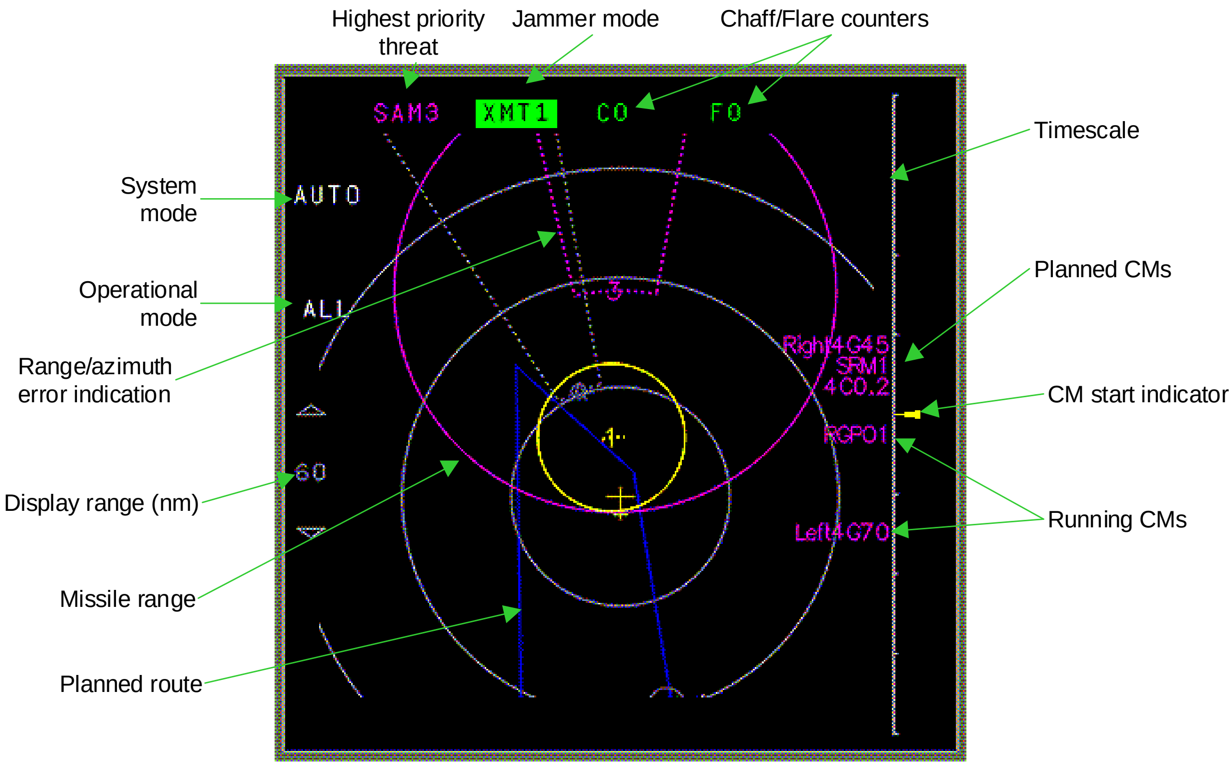

Figure 4 SP EW manager threat display

4 SP EW manager evaluation

4.1 Evaluation set-up

In order to be able to evaluate the management concept, four different scenarios were created: 2 for a jet fighter and 2 for a four-engine turboprop aircraft. Each aircraft type was fitted with a representative set of EW sensors and CM assets. 8 different threat types were defined for use in the scenarios: 4 radar guided SAM systems, 3 infrared guided SAM systems (one fitted with a search radar, and 2 man portable systems) and 1 AAA system. In order to avoid classification of the project results, fictitious data were used for the threat characteristics, as well as for the aircraft and sensor data. In the evaluations, 11 missions were "flown" using the four scenarios. The different missions incorporated different operational modes, different altitudes, and different sets of intell information.

4.2 Evaluation findings

- Accurate sensors are of paramount importance, both with regard to identifying and to locating the threat. This becomes a greater issue when multiple threats are detected. Identification is important to optimise performance, and to reduce ambiguity. Accurate locations are important to optimise manoeuvre advises, and to get better threat level computations. Sensor output must be accurate enough to enable earth-stabilised location information. Otherwise, the threats will move around during manoeuvres, which may lead to erroneous advises.
  Sensors and MSDF should provide some form of memory tracking. In the demonstrator, a threat disappears (and associated CMTs are cancelled) after two seconds when it is manoeuvred outside the antenna patterns of the sensors. Memory tracking should also account for the loss of tracks due to line of sight limitations: threats that are (temporarily) shielded by the terrain should remain available even though they are not currently a real threat. When they are detected again, this could speed up identification. Also, they remain available for display, so the crew remains aware of their existence. Obviously, this requires a digital terrain model, and accurate position information.
- Inclusion of manoeuvre advices proved to be a major difficulty in realising SP EW manager. Because it is not allowed to execute manoeuvres automatically, it should be checked whether or not the crew is correctly following (or even: intends to follow) the advice. It was not possible to devise a satisfactory solution within the scope of this project. As a stop-gap solution, a “crew-reject” button was introduced, enabling the crew to reject a CMT if they are not able to follow the advice.
  As a result, it cannot be predicted when an advised manoeuvre will start, and even less when it is going to be finished. Therefore, if the crew does not reject the CMT, execution of follow-on actions is postponed until a prescribed condition (e.g. azimuth with regard to threat) is met. If these conditions are not met, the actions stays on the schedule until the threat disappears. Meanwhile, no other CMT is planned because the threat is already being “countered”.
- It is not possible to regard the MSDF and RM modules as totally independent entities. Some form of feedback from the RM to the MSDF remains necessary. This came the most clear in threat level changes that were caused due to RM-prompted manoeuvres (e.g. because the threat has limited tail-on capability), which resulted in the CMT to be cancelled. To prevent this from happening, the MSDF must “know” that an azimuth change is a result of the running CMT, and threat level changes due to this azimuth change are therefore not allowed. In addition, the RM must be able to cue the MSDF to collect additional data on a specific threat.
- Due to the limited capabilities of the current missile warning systems and MSDF, only basic missile countermeasures can be performed. More sophisticated countermeasures would

require the introduction of dynamic missile modelling within SP EW manager. This was outside the scope of the project.

4.3 Other experiments

After completion of the evaluations in the SP EW manager project, the demonstrator was, in an adapted form, used in Human Factors evaluations as part of the POWER (Pilot Oriented Workload Evaluation and Redistribution) project. This project aimed at demonstrating a generic Crew Assistant (CA) environment and individual tactical decision support tools to pilots in a simulated environment. This time NLR's full-scale F-16 simulator facilities were used, showing the EW manager display as an alternative Horizontal Situation Display (HSD). Nine RNLAF F-16 pilots participated in this study.

Results of this project were briefed in the RTO SCI-113 Lecture Series number LS 227, entitled "Tactical Decision Aids and Situational Awareness", in November 2001. This project focused on usability issues, pilot acceptance and Situational Awareness (SA). With regard to the EW manager, it was found that pilots were sceptical about the usability of the manager, but after using it in the simulator they were more convinced (after using NCMM) that:

- It performs like a real pilot.
- Integration in the aircraft may be adequate.
- It does not show too much irrelevant/distracting details.
- It is capable of taking pilot personal preferences into account.
- It is sufficiently sensitive to specific mission demands.

The most important results concerning the system application (use) were that pilots, after using the system:

- have confidence in the system and will as such use it.
- will not necessarily (eventually) loose EW related skills when using it.
- do not expect it to cause task saturation or -fixation.

Observations indicate that SA improved when using the EW manager, and fewer errors were made in controlling the EW assets. Complete results can be found in the Lecture Series report: RTO-EN-019 AC/323(SCI-113)TP/41.

5 Future Prospects

After formal completion of the SP EW project in October 2000, demonstrations of the system were given to the RNLAF and the RNLN. As mentioned in section 4.3, the application was used in the POWER project evaluations in 2001. The logical next step would have been to develop interfaces with real EW hardware, and to evaluate the system in an EW trial. Plans were made to realise this, but unfortunately they never materialised for lack of funds.

Currently, discussions are ongoing to define a follow-on to the POWER project. Further development of the SP EW manager could be part of this effort.

6 Conclusion

The major goal of the project, to develop and demonstrate a concept for EW management, was met. Even though not all functional requirements could be implemented to the full, the *concept* for EW management was shown to be effective. Co-ordinated action of all assets is available, and except for the execution of tactics, crew interaction is not necessary (although it remains possible) for execution of countermeasure techniques. Exact timing of chaff and flare dispenses during a manoeuvre is possible, as well as exact balancing of start and duration of jamming with dispense actions. Determination of enhanced effectivity and reduced workload could not be established using the current demonstrator. This will require a more sophisticated test environment. However, successful project completion does not mean that the developed SP EW manager *application* is suitable for operational use, or even complete yet. It is very much a prototype to demonstrate the capabilities of the developed concept. As such, it has been successful, but it's only the first step in developing an operational SP EW manager. The additional research in the POWER project has shown that pilots indicated that an EW manager is a valuable asset, that helps improve Situational Awareness and reduce errors.